Retrieving Semantic and Syntactic Word Properties:

ERP Studies on the Time Course in Language Comprehension

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Retrieving Semantic and Syntactic Word Properties:

ERP Studies on the Time Course in Language Comprehension

een wetenschappelijke proeve
op het gebied van de Sociale Wetenschappen

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door
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PREFACE

It took a while to get here. This thing called *dissertation* is almost done and I have to say that I am a bit astonished at that. But then, skimming through the prefaces of previous dissertations, I can almost hear their authors saying "Join the club". This is a happy time, a time to look back and thank the people who brought me here.

One of the most important persons in shaping this dissertation is, of course, my supervisor Peter Hagoort. He gave me the opportunity to learn about psycholinguistic ERP research in an extraordinary scientific environment and offered his rich experience as an investigator. In particular, he reminded me not to get lost in details (still trying), provided a clear view on data that confused me, and put things into perspective by making snappy remarks about the reviewers' comments. Thank you for all that.

There are some people who innocently got entangled in my dissertation project. Rasha Abdel Rahman, Mike Coles, Ardi Roelofs, and Miranda van Turennout deserve much credit for looking at data with me, discussing interpretations, and helping to develop ideas for new experiments.

I want to thank Werner Deutsch for introducing me to psycholinguistics and showing me the way to the Max Planck Institute. I hope you can be a little proud of having contributed to my becoming a psycholinguist.

Good technical support is invaluable, as every experimenter knows. John Nagengast and Johan Weustink kept my experiments running through fast and friendly help and René de Bruin never got tired of adapting his ERP program to my special requests.

Another essential asset is a good social network – or, in other words, a bunch of friends. At the institutes, I met many colleagues who became my friends and my network was completed by "outsiders" who I met *via via*. My supervisors on getting to know Dutch life were Anne Pier (E.) Salverda and Jan (Bommel) van de Mortel. Despite my being a humourless German who had stolen the WK '74 they accepted me in their middle. I hope you enjoyed the company of this particular *Duits dier* as much as it enjoyed yours.

Dannie van den Brink witnessed my very first steps in the Max Planck Institute in the fall of 1997, when I was an intern and she a student assistant in the Speech Production group. When I joined the Neurocognition of Language project two years later it was a lucky coincidence that I found her as a colleague there, because in the years to come she would provide much support just by being her cheerful self and non-rhetorically asking "Hoe gaat'ie?" every once in a while. Simone Sprenger is also a long-time companion of my PhD

student time and the dinners at her and Hedderik's place together with Mandana created a feeling of being at home that contributed very much to my finishing this thesis. What is more, she revealed a prophetic gift regarding being my paranimf. Once, as I uttered doubts about getting my thesis done, she said: "I will personally make sure you get a PhD song." I thought I had a crushing argument against that, saying: "You will finish before me, so you will not be around." Although you did finish before me, you returned to Nijmegen and you are around now, proving me wrong – exceptionally enough, I am happy with it. Lieve Dannie, Liebe Simone, thank you for all of the above and for being my *paranimfen*.

In the summer of 2000, Mandana Seyfeddinipur and I found ourselves chatting in the courtyard of the Max Planck Institute, which started a much cherished friendship. It is built on her warm personality, my home-baked cake, and sharing the ups and downs of the life as a PhD student. In the course of the last year, we could watch each other's PhD theses come to a happy ending. See you in the sun!

Starting with the fall of 2001, I spent most of my time at the Donders Centre and there were friends to be made, too. Karl Magnus Petersson habitually stepped into my room by asking "What's up?!", initiating scientific discussions, with him providing the more insightful remarks, or just a night at the movies. Markus Bauer showed that it was possible to work a lot and have fun at the same time, sometimes dragging me along in his slipstream. Ole Jensen and Freya Johnsen Jensen created an irresistible mix of Danish and American hospitality and I enjoyed being a guest in their home many times (although the cake I brought the first time had kind of gone wrong). Together with Christian Forkstam and Atsuko Takashima, I delighted in preparing and consuming fine food, no matter if the houseboat was tilted or dancing on the waves. These are just little snippets of memory, but I hope you all know how much I appreciate you.

Back in my home town Braunschweig there was a trusted group of friends who offered roots into the past and a perspective on life from outside the scientific Nijmegen circle. My best friend Lars Dobrovolschi showed great endurance on the telephone, so that we could keep each other updated on our lives. Friendship is when you just don't know why you always have a good time together! Ingo Kanwischer was my travel companion on many a journey and a faithful visitor to Nijmegen, getting me out of my routine, and he fed me with the newest *Gute Musik*. Petra Metzenthin provided for long breakfasts with lots of chatting and, after having moved to Zürich, allowed me to relax in that beautiful city when it was most needed. Let there be many happy returns!

There are many more who made life pleasant and were a big help, including all my dear colleagues from the PhD groups of the Max Planck and the Donders. Special thanks to: Anita Wagner, Pamela Perniss, Sabine Schneider, Valesca Kooijman, Marlies Wassenaar, Frauke Hellwig, Jelle van Dijk, Dasha Osipova, Aliette Lochy-Sutovsky, and Chisato

Kajita. I am sure I have forgotten several people who deserve to be mentioned here. Please forgive me – come to my party and I will apologize in person as we have a drink together.

Schliesslich will ich meinen Eltern danken. Ihr habt mich meinen Weg gehen lassen, ohne viel Fragen zu stellen. Durch meine Studien- und Doktorandenzeit habt ihr mir oft unter die Arme gegriffen – und das selbst, obwohl ich wahrscheinlich nie gut erklären konnte, was ich da eigentlich tue, an der Universität oder jenem Institut in den Niederlanden. Dafür vielen, vielen Dank.

Oliver

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INTRODUCTION

Chapter 1

Comprehending spoken or written language means to obtain a meaningful interpretation from a physical signal. The interpretation represents matters beyond the physical signal, matters as varied as what happened during the vacation of your best friend, how to format a manuscript for submission to a scientific journal, or which supermarkets are open on Sundays. Most of the time, we make the transition from perceiving to understanding in a fast and effortless manner. When we listen to somebody or read a text, our personal experience is not that we hear a series of sounds or look at a pattern of dots and lines - the meaning rather seems to pop up in our mind immediately. However, this impression is deceiving. Before we arrive at an interpretation, we invoke a diverse set of knowledge and past experience. It is the result of all those years we needed to acquire language during childhood. As with many highly automatic skills, failure can make us realize the wealth of resources and operations we actually need. While we are used to function smoothly as language comprehenders in our native language, we get into trouble when we encounter a foreign language. We go on vacation, get off the airplane, mix with the sunbathed crowd – and suddenly it is all sounds, no meaning. We cannot even tell where one word ends and another one starts. Going to a newsstand and picking up the local newspaper, we seem to be one step further. Spaces neatly separate the words. Still, we could not tell whether there is a typ – let alone, what it all means. If we are curious or stubborn enough to keep on “reading”, we might notice that some words appear repeatedly. These words become familiar and every time we see them now they create some feeling of recognition. Nevertheless, there is still a lot missing, a lot the permanent residents of our vacation spot know about their language (though being largely unaware of it) and we do not know.

What constitutes a particular word seems to have at least two sides: its form and some hidden content. For speakers of a particular language, the form of a word gives access to that hidden content. Investigators of word recognition have captured this notion in the term *mental lexicon*. The sensory input from spoken or written language is compared to form-based characteristics of lexical entries. Each lexical entry contains further information associated with the particular word, which becomes available upon a match. This includes the meaning of the word and its syntactic properties. Word meanings serve as elements that shape the overall meaning of a discourse or text. When we read *The group enters the hotel*, we know that there are several people involved, because the word *group* – by virtue of its meaning – refers to a multiplicity of elements. From the word *enters* we know that the *group* is moving and that the persons will probably end up inside the *hotel*. The meaning of a word is not an isolated representation – words have various semantic relations among each other (cf. Komatsu, 1992). A *hotel* and a *barn*, for example, share certain properties. They are both man-made structures, have a roof, some kind of entrance and so forth. For some words, the sharing of semantic properties is related to the membership in a common semantic category – in the case of *hotel* and *barn*, this is the category *building*. Models of semantic representation differ in the way they capture semantic relations. Distributed models use nodes to represent semantic features, while the meaning of a particular word is equivalent to some activation pattern across the feature nodes. Semantic relatedness corresponds to the activation of a similar set of feature nodes (e.g., Plaut & Shallice, 1993). In classic spreading activation models (Collins & Loftus, 1975), the meaning of a word is represented through a single node. If words stand in a semantic relationship, they are connected and can activate each other. In this way, words can be linked to their semantic properties or semantic category.

Syntactic word properties determine how words relate to each other and how they combine into sentences, irrespective of word meaning. A prominent syntactic word property is the lexical category, which distinguishes word classes such as verb, noun, adjective, preposition, etc. While verbs feature as the predicate of clauses, nouns can function as subject or object of the verb, and adjectives can modify nouns. Such relations often go with morphological processes. In English, for example, the number of the subject noun determines the number of the verb. In other words, the subject noun and the verb have to agree in number. Accordingly, singular number results in *The group enters the hotel* and plural number results in *The groups enter the hotel*. Another syntactic word property is the grammatical gender of nouns. Numerous languages of diverse origin have grammatical gender, as for example Dutch, Italian, Hebrew, and Swahili (cf. Corbett, 1991). English only uses natural gender (i.e., sex) and shows corresponding gender agreement phenomena. While *actress* goes with the personal pronoun *she* and *actor* goes with *he*, all sexless nouns simply go with *it*. In contrast, languages with grammatical gender divide all nouns into various classes. Speakers of such languages have to know the gender of every noun, in order to comply with gender agreement rules. The Dutch language, for example, knows two grammatical genders, labeled common and neuter gender. In the singular, the definite article of common gender nouns takes the form *de*, while it takes the form *het* for neuter gender nouns. Accordingly, the sentence *The group enters the hotel* becomes *De groep betreedt het hotel* in Dutch, since *groep* has common gender and *hotel* has neuter gender.

Semantic and syntactic word properties, which become available in the course of word recognition, form the input to the processes that assemble higher order syntactic and semantic structures. The overall interpretation further incorporates general world knowledge, the current discourse situation, and knowledge about communicative intentions. Most researchers would agree with a general order of processing stages in language comprehension, where processing of form aspects leads to word recognition and the retrieval of lexical information, which is in turn integrated into more complex structures (Cutler & Clifton, 1999; Perfetti, 1999; but see Elman, 2004).

The retrieval of semantic and syntactic word properties occurs at the interface between word recognition and sentence processing and signifies an important transition in the course of language comprehension. As the word turns from a perceptual unit into a carrier of semantic and syntactic information, it becomes possible to construct a meaningful and complex message from a string of words. This thesis is concerned with the details of accessing semantic and syntactic word properties during language comprehension. The central issue is whether the retrieval of semantic and syntactic properties might occur in a particular temporal order. In other words, does semantic retrieval occur before syntactic retrieval, in the opposite order, or in parallel? A complex cognitive activity such as language comprehension relies on a multitude of informational resources and processes, as outlined above. Regarding the organization of such a complex activity, one of the main questions is whether the access to representations and related processing occurs in a particular order or in a parallel manner. It seems clear that the presentation of a word will first engage form related processes, ensued by the access to semantic and syntactic word properties, which are then integrated into higher order semantic and syntactic structures. However, regarding the access to word properties and the integration into higher order structures, the issue of serial or parallel arrangement of the respective semantic and syntactic aspects appears to be more open. The literature on the construction of higher order syntactic structures (i.e., parsing) knows well-articulated, contradictory positions regarding this issue (Frazier, 1989; Friederici, 1995, 2002; Forster, 1979; MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell & Tanenhaus, 1994; see below). In contrast, there seems to be no model of language comprehension that makes strong claims regarding a serial or parallel arrangement of the access to semantic and syntactic word properties. The investigation of the time course of access to semantic and syntactic word properties can be helpful in specifying this part of the language comprehension system. For a first approximation, the study will focus on words outside of the sentence context.

Taking a tentative look at the sister discipline, speech production research, one can find a preference for a serial arrangement, with access to semantic word properties preceding access to syntactic word properties. A variety of models conceptualizes speech production as running through layers of an extended network, with each layer containing a specific kind of linguistic knowledge. Most models include distinct layers for semantic, syntactic, and phonological representations of words (Dell, 1986; Harley, 1993; Kempen & Hoenamp, 1987; Levelt, 1989; Levelt, Roelofs, & Meyer, 1999; Stemberger, 1985; but see Caramazza, 1997). The first layer is semantic in nature, containing *concepts*, that is, representations of word meanings. Concepts become active if they match the communicative intention of the speaker. Activation spreads from concepts to corresponding *lemmas*, which make up the next layer and contain the syntactic properties of words. Based on the now available syntactic properties, word order and other syntactic relations of an utterance can be established. From the lemmas, activation spreads to the *word form* level, where the sound shape of words is determined. Thus, semantic and syntactic aspects of words are located in separate layers, with access to semantic word properties occurring before access to syntactic word properties. Note, that this ordering is not meant to be strictly serial, but that there is a cascaded or interactive activation flow between the semantic and lemma layer. Interestingly, it has been suggested that speech production and language comprehension might share the semantic and syntactic word representations (Branigan, Pickering, & Cleland, 2000; Bock & Griffin, 2000; Levelt et al., 1999). Levelt et al. write, "the perceptual and production networks coincide from the lemma level upwards" (p. 7), indicating a common lemma level and concept level. One can assume that the direction of processing in comprehension is reversed in relation to that in speech production. In comprehension, processing starts with a perceived word shape and heads towards a conceptual understanding, whereas in production it starts with a conceptual intention and heads towards word shape. According to this reversed direction of processing, one might expect syntactic word properties to be available earlier than semantic properties, but so far, there was no firm evidence whether this is indeed the case.

As indicated above, the parsing literature features opposing positions regarding the time course with which syntactic and semantic information can affect parsing. The following contains a short description of these positions and a speculative suggestion about how a serial or parallel arrangement in parsing might be related to the retrieval of word properties. Some models assume that syntactic lexical information has an earlier influence than semantic lexical information. In particular, Frazier (1989) and Friederici (1995, 2002) claim that only lexical category guides the first parsing attempt. Other syntactic information, such as grammatical gender or the subcategorization of verbs (transitive/intransitive), as well as semantic properties and discourse context are supposed to have a later impact. The model of Forster (1979) contains three serially arranged processors. The lexical processor maps the perceptual input onto lexical entries. The parser then receives the syntactic lexical information of the identified word and uses it to construct a syntactic structure. Chunks of syntactic structure are subsequently fed into the message processor which constructs a conceptual representation, employing semantic lexical information and inferential mechanisms. The message processor also resolves ambiguities in the syntactic structure with the help of semantic information. In contrast to these so-called syntax-first models, constraint-based approaches to parsing assume that all kinds of different information are immediately exploited as soon as they are available (MacDonald et al., 1994; Trueswell & Tanenhaus, 1994). This includes syntactic and semantic constraints from lexical sources or higher order representations, as well as the frequency of certain syntactic constructions in a language. Thus, the parsing literature offers models that argue for a certain seriality regarding the usage of syntactic and semantic information, but also models that argue for parallel usage. Given that semantic and syntactic word properties both are relevant for parsing, one could speculate that the time course issues of word property retrieval and parsing are related to each other. An optimal design for the whole language comprehension system might include a close temporal coupling between the retrieval of word properties and the parsing operations that make use of them. Accordingly, a syntax-first parser would correspond best to first retrieving syntactic word properties and then semantic word properties. As the constraint-based models do not commit to a principled order in using lexical syntactic and semantic information for parsing, speculations about a correspondence with the retrieval order of word properties might seem futile. Nevertheless, any kind of order in the retrieval of syntactic and semantic word properties would give a principled temporal advantage to one kind of information. As such an advantage goes against the spirit of the constraint-based approach, parallel retrieval might be the most appropriate arrangement.

In order to investigate the time course of accessing syntactic and semantic word properties for single words, the present study makes use of electrophysiological and behavioral techniques. This involves in particular the two-choice go/nogo paradigm and the recording of specific event-related potentials (ERPs), namely the lateralized readiness potential (LRP) and the inhibition-related N2 effect. The usage of these ERPs allows the monitoring of covert cognitive processes with high temporal resolution. Van Turennout, Hagoort, and Brown (1997, 1998) introduced the LRP methodology to language research in their investigation of time course questions in speech production. Schmitt, Münte, and Kutas (2000) complemented this methodology by additionally using the N2 effect to monitor the time course of lexical information retrieval. In the following, a short introduction to ERPs will be given.

Event-related Potentials

ERPs offer the possibility to monitor brain activity non-invasively and with high temporal precision, in the order of milliseconds (cf. Picton, Lins, & Scherg, 1995; Coles & Rugg, 1995). They reflect the electrical activity of large neuronal ensembles, occurring in association with a certain event like the presentation of a stimulus. The electromagnetic field of individual neurons is so small that it can be measured only intracranially. However, if a group of neurons is oriented in the same direction and shows synchronous activity, the fields of the individual neurons summate and can create a field that is strong enough to reach the scalp. This can be measured as potential differences between electrodes placed on the surface of the head. Recordings of these potential differences and their changes over time are called electroencephalogram (EEG). The spontaneous EEG for a given electrode is a mixture of activity from numerous neuronal ensembles and reaches amplitudes of 10 to 100 µV, that is, 0.00001 to 0.0001 Volt. ERP activity associated with a particular sensory or cognitive function has even smaller amplitudes, ranging from 1 to 10 µV, which makes it practically invisible in the spontaneous EEG. A common technique to improve the signal-to-noise ratio and extract the ERP is to average EEG activity over trials with similar processing demands. In order to do that, one defines epoques of recorded EEG with respect to a particular event. In case of language comprehension, the onset of word presentation typically serves as critical event, which defines time zero for all trials. Ideally, the averaged waveform reflects the ERP, that is, neuronal activity associated with the specific event. The averaging procedure has the underlying assumption that an event triggers a train of potential changes with a more or less constant shape and timing across trials, while potential changes due to unrelated activity occur randomly and cancel each other out.[1]

The ERP consists of a series of positive and negative peaks, which can be characterized according to polarity, latency, and amplitude. In describing peaks, one often refers to their polarity and latency. The well known P300, for example, features *P* because of its positive polarity and *300* because the peak typically occurs around 300 ms. Analogously, the N400 features *N* for negative polarity and *400* for a peak latency of 400 ms. An alternative system for labeling also refers to polarity, but indicates the ordinal position of positive and negative peaks instead of their latency. The perception of an auditory target stimulus, for example, typically results in a sequence of ERP peaks labeled P1, N1, P2, N2, and P3. Sometimes labels also refer to the supposed function of the indicated ERP. The readiness potential, for example, occurs before voluntary or cued movements and is thought to reflect preparatory activity. For research purposes, the EEG is usually recorded from several electrodes distributed over the surface of the head, often placed at standardized positions (e.g., American Electroencephalographic Society, 1991). By comparing at which electrodes an ERP occurs or has its maximum amplitude, one can establish its so-called topography, which is another important characteristic in describing ERPs. A *frontal* ERP, for example, has the largest amplitudes at electrodes placed at the front of the head. A *left-lateralized* ERP is strongest at electrodes on the left side of the head. One has to be aware, that activity measured at a certain position on the scalp does not necessarily originate from the brain structures directly underneath it. The electrical fields generated by neuronal ensembles lead to electrical currents in the surrounding tissue, which eventually cause the potential differences on the scalp measured as EEG. Currents might flow in such a way that they carry activity to electrodes which are quite distant from the original source. Despite the complicated relationship be-

1. The averaging procedure extracts activity that is both time-locked and phase-locked. Event-related activity that is not phase-locked gets suppressed. Such activity actually can contain valuable information for cognitive scientists and methods exist to extract it (cf. Pfurtscheller & Lopes da Silva, 1999). However, the current thesis only contains analyses of conventional ERP data.

tween electrode and source location, the topography of ERPs can provide evidence about differences between experimental conditions.

The ERP offers a wealth of information that can help us investigate the effects of experimental manipulations (Rugg & Coles, 1995). On the most unspecific level, we can infer that a processing difference between two experimental conditions exists, if we find any kind of difference between the ERPs derived for these conditions. A simple divergence between the waveforms, at any electrode, is sufficient, as long as we provide statistical control. This is often assessed by subtracting one waveform from the other, resulting in a so-called subtraction waveform. If the amplitude of the subtraction waveform significantly differs from zero, this is equivalent to the separate waveforms diverging. One often speaks about an *ERP effect*, if a significant divergence between waveforms occurs. Note that a failure to find a difference does not allow the conclusion that there was no processing difference. One has to keep in mind that the ERP picks up only specific parts of brain activity. Furthermore, the time at which the waveforms start to diverge can serve as an upper bound for estimating the moment at which the processing difference occurred. In other words, the processing started to be different at least at the onset of the divergence – it might have been earlier, but not visible in the ERP. The comparison of activity across electrodes is also useful. Differences in topography are commonly interpreted as reflecting the differential engagement of neural structures (but see Urbach & Kutas, 2002). The stronger activity of one neuronal ensemble should only lead to an overall difference in amplitude. However, the activity of an additional ensemble in one condition should change the topography, especially if the additional source is spatially well separated from the other active sources. Likewise, if one source showed the same activity across conditions, while the activity of another source varied, this should also result in a different topography. By making the assumption that different neuronal ensembles correspond to different functional processes, one can make a more powerful inference based on topography. A topographical difference between conditions would then signify a difference in functional processes.

The kind of inferences listed so far do not presuppose that we know the exact functional meaning of the peak or stretch of ERP where we find an effect. If we have designed the experimental conditions in such a way that they differ only along one aspect, we can assume that the differences we found relate to that particular aspect. More specific inferences become possible, if one focuses on well-defined parts of ERP activity that have a functional interpretation based on previous research. A prominent concept in this context is that of *ERP component*. Although this term is sometimes used for any peak that is clearly distinguishable in a waveform, stricter definitions exist, demanding functional specificity (cf. Coles & Rugg, 1995; see below). Suppose, we know the functional process underlying a particular component, which is defined as a negative peak occurring at frontal electrodes. We might then conduct an experiment that engages this process in two different experimental conditions. If the component shows a different latency for the two conditions, we can infer that the associated process took longer in one condition as compared to the other. Should we also know that the amplitude of the component indicates the intensity of the associated process, we can make corresponding inferences in addition. Alas, establishing the functional underpinnings of a component is quite difficult and for many components it is an on-going process. One of the problems is that ERP activity at a particular electrode can originate from several neural sources and that these sources might be related to different functions. Ideally, one would want to disentangle the different contributions by localizing the respective sources. However, source localization turns out to be a difficult undertaking, especially for long-latency ERPs, which are associated with higher cognitive functions. Within a widely known functional approach to component definition, a well-defined component is supposed to have a specific polarity, topography, and latency (Donchin, Ritter, & McCallum, 1978). However, one should note that latency might vary substantially for long-latency cognitive ERPs – which makes them useful in investigating time course issues. The functional aspects of a component can be investigated by testing the influence of certain variables and by relating the changeable features of the component (e.g., amplitude) to other dependent measures (e.g., response time, accuracy).

The ERP measures used in this study are the LRP and the N2 effect. In what follows, the rationale for their usage in the investigation of time course issues will be explained. This includes background information on these ERPs, accompanied by a summary of the studies by Van Turennout et al. (1997) and Schmitt et al. (2000), respectively.

The LRP and Time Course Monitoring

The LRP is regarded as an index of motor response preparation (Coles, 1989; Eimer, 1998). It is derived from the readiness potential (RP), or Bereitschaftpotential, which was first described by Kornhuber and Deecke (1965). In their seminal study, they recorded EEG activity at the scalp in the course of voluntary finger movements. A slow ramp-shaped negative potential developed before movement execution, reaching its maximum around the time of movement onset. Vaughan, Costa, and Ritter (1968) showed that the RP for unimanual responses is largest at electrodes above the motor cortex contralateral to the moving hand, corresponding to the functional neuroanatomy of movement preparation. A few computational steps can extract the lateralized part of movement-related activity, resulting in the LRP. De Jong, Wierda, Mulder, and Mulder (1988) proposed the following formula:

$$\mathrm{LRP} = \mathrm{Avg}(C3' - C4')_{\text{right hand}} - \mathrm{Avg}(C3' - C4')_{\text{left hand}}$$

The electrodes C3’ and C4’ are seated above the left and right motor cortices, respectively. First, one subtracts the waveform of the left electrode (C3’) from the waveform of the right electrode (C4’) for all trials. This results in the left-lateralized part of the EEG. Separately for left and right hand trials, averages are then computed for these subtraction waveforms. Finally, the average of the left hand trials is subtracted from the average of the right hand trials. Through this last step, lateralizations are eliminated that occur on the same side for both left and right hand trials. In a language-related task, for example, one might expect some left lateralization to occur because of hemispheric processing differences. In contrast to such constant lateralizations, lateralizations that change in correlation with the required response hand add up. A LRP with negative polarity indicates correct preparation for the instructed response side, whereas a LRP with positive polarity indicates preparation for the erroneous response side.

An interesting property of the LRP is that it is very sensitive to the time course with which response-relevant information becomes available. In combination with the two-choice go/nogo paradigm, one can investigate the temporal dissociation of different kinds of information. By way of instruction, two dimensions of the same stimulus are mapped onto two response dimensions. One stimulus dimension determines whether to respond with the left or right hand and the other stimulus dimension determines whether a response should be executed at all (therefore go/nogo). Miller and Hackley (1992) presented letters to their participants and used a stimulus set where left/right information (letter identity) was easier to discriminate than go/nogo information (letter size). They could show that correct motor preparation as indexed by the LRP started even on nogo-trials, although being smaller and shorter than on go-trials. The letter identity information governing hand selection must have been available to start up motor preparation. Nogo-information from letter size, being harder to obtain and thus later available, could inhibit motor preparation only at a later point in time. Osman, Bashore, Coles, Donchin, and Meyer (1992) manipulated the difficulty of both the left/right decision and the go/nogo decision. Onset time of the LRP increased with the difficulty of the response hand decision, whereas the time when the nogo-LRP returned to baseline increased with the difficulty of the go/nogo decision. Thus, the LRP – especially the nogo-waveform – can reflect the availability of different kinds of information during the time course of processing, with the temporal resolution of a few milliseconds characteristic of ERPs.

Van Turennout et al. (1997) conducted the first study to exploit the LRP for a psycholinguistic question. They investigated the time course of access to semantic and phonological word properties in speech production. Participants performed a picture-naming task in Dutch, with additionally a two-choice go/nogo task on some proportion of the trials. For the two-choice go/nogo task, they had to classify the depicted entities according to the semantic category (animal/object) and the last phoneme of the picture name. In the first experiment semantic classification determined response hand and phonological classification determined response execution (go/nogo decision). The LRP in the nogo condition displayed significant motor preparation, but smaller and for a shorter period of time than for actually executed movements. Thus, semantic information instructed the preparation of a motor response before phonological information eventually stopped this process. Regarding the processing order in speech production, this suggests that semantics is available before phonology, corresponding to the assumptions in theories of speech production, as indicated above. However, the work of Smid, Mulder, Mulder, and Brands (1992) provides evidence for the strategic use of information in the two-choice go/nogo paradigm, opening the possibility for alternative accounts. In one possible scenario, participants might organize the retrieval of stimulus attributes serially: First, they focus on extracting the information determining response hand, to start up movement preparation as soon as possible. Subsequently, they try to retrieve the information relevant for response execution. In another scenario, both relevant stimulus attributes might be available simultaneously, but their usage is organized serially: Information determining response hand is put to use first, to initiate movement preparation, and then information determining response execution is used to decide whether to continue or to abort preparation. Thus, a situation with no inherent order to the availability of semantic and phonological information might still lead to the observed nogo-LRP result. In order to rule out these strategic accounts, Van Turennout et al. (1997) conducted a second experiment where they reversed the assignment of stimulus to response dimensions: phoneme identity now determined response hand and semantic category determined response execution. According to the speech production account, the early available semantic information should block response preparation on nogo trials before phonological information can feed into motor preparation – no significant LRP activity should show up on nogo trials. The strategic accounts predict that the stimulus dimension determining response hand selection – this time phonology – would be retrieved or used first, initiating some motor preparation before the decision on response execution would take place. This should result in significant LRP activity on nogo trials. Analysis of the LRP for nogo trials found no significant motor activity, excluding the mentioned strategic accounts. Several studies have since then used the LRP successfully to address time course questions in speech production (Abdel Rahman & Sommer, 2003; Abdel Rahman, Van Turennout, & Levelt, 2003; Schmitt et al., 2000; Schmitt, Schiltz, Zaake, Kutas, & Münte, 2001; Van Turennout et al., 1998).

The N2 and Time Course Monitoring

Schmitt et al. (2000) introduced another ERP component for monitoring the time course of language processing, the inhibition-related N2. When participants have to respond to some stimuli (go), while withholding a response to other stimuli (nogo), the ERP for nogo-trials displays a negative peak of several microvolts with a frontocentral distribution (Gemba & Sasaki, 1989; Kok, 1986; Pfefferbaum, Ford, Weller, & Kopell, 1985; Simson, Vaughan, & Ritter, 1977). Such nogo-related activity has also been found with MEG (Sasaki, Gemba, Nambu, & Matsuzaki, 1993) and with field potential recordings from the prefrontal cortex of monkeys (Sasaki, Gemba, & Tsujimoto, 1989). The peak latency can vary extensively among experiments, from 135 ms after stimulus in a color discrimination task (Sasaki et al.,

1993) to 480 ms in a visual vowel-consonant discrimination task, which included occasionally degraded stimuli (Kok, 1986). Several researchers have suggested that the nogo-related negativity reflects response inhibition (Eimer, 1993; Falkenstein, Hoormann, & Hohnsbein, 1999; Jodo & Kayama, 1992; Kok, 1986; Van Boxtel, Van der Molen, Jennings, & Brunia, 2001). Since go- and nogo-trials do not only differ with respect to the demand for inhibition, but also with respect to the demand for an overt response, one could argue that the divergent ERP activity actually derives from motor-related processes. To investigate this, Pfefferbaum et al. (1985) designed a non-motoric task. Participants had to count certain stimuli covertly, while they had to refrain from counting another category of stimuli. This produced similar ERP signatures as a go/nogo task with overt go responses, including a negative deflection that was stronger for no-count stimuli than for count stimuli. Further support for the inhibitory interpretation of the N2 comes from the study by Sasaki et al. (1989) who trained monkeys in a go/nogo task with color stimuli. Surface and depth electrodes, implanted in the brain, picked up nogo-related activity in prefrontal cortex, 110 to 150 ms after stimulus onset. In the second phase of the study, cortex was electrically stimulated through the electrodes during task performance, in varying areas and at varying time points after stimulus onset. This resulted in the delay or total suppression of the learned movement on go-trials, and most effectively when electrical stimulation took place in the same areas and at the same time points which had featured nogo-related activity before. Thus, the nogo-related negativity found in prefrontal areas seems to be functional in preventing the execution of movements. However, some researchers have recently proposed that the N2 effect reflects conflict monitoring rather than inhibition (Donkers & Van Boxtel, 2004; Nieuwenhuis, Yeung, Van der Wildenberg, & Ridderinkhof, 2003). Manipulating the probability of response alternatives in different tasks, they found that the non-dominant (i.e., less frequent) response always resulted in the larger N2 amplitude, even if it was a go response rather than a nogo response. They suggest that the go/nogo status should have had a stronger influence than the probability of response alternatives, if the N2 was related to inhibition. According to their view, the N2 rather reflected conflict, which was bigger for non-dominant responses because they went against the general response preference. While the interpretation of the N2 might be an open issue, it is still useful for the investigation of time course issues. The time point at which go- and nogo-waveform diverge can serve as upper time estimate for the availability of the information that determines the go/nogo decision.

Thorpe, Fize, and Marlot (1996) applied the N2 to the estimation of cognitive processing time, in particular regarding the process of object identification. Participants saw photographs and had to push a button when an animal was part of the scene and had to withhold the response when no animal was present. A typical nogo-N2 appeared at frontal sites, having its onset at 171 ms after stimulus presentation, when the grand average ERP became significantly more negative for nogo-trials than for go-trials. Thorpe et al. (1996) interpreted the onset latency as an upper limit to object identification time, arguing that the information that no animal was present had to be available in order to start up inhibitory activity on nogo-trials.

Following the same rationale, Schmitt et al. (2000) used the N2 to compare the time course of semantic and phonological processes in speech production. Their study replicated the one by Van Turennout et al. (1997) in German: In one version of the two-choice go/nogo task, response hand depended on the depicted object's semantics, while the go/nogo decision depended on its phonology; in the reversed version, response hand depended on phonology, while the go/nogo decision depended on semantics. The N2 was visible for both versions and to obtain net inhibition effects, the go-trial averages were subtracted from the respective nogo-trial averages. The onset and the peak of the N2 net effect occurred significantly earlier when semantics determined the inhibition-relevant go/nogo decision than when phonology did. This provided evidence for the earlier availability of semantic information in comparison to phonological information. The LRP analysis corroborated this result. Preparatory activity on nogo-trials emerged when semantics determined response hand but not when phonology determined response hand, paralleling the results of Van Turennout et al. Schmitt and co-workers have employed the inhibition-related N2 in further studies, investigating time course issues in speech production and auditory language comprehension (Rodriguez-Fornells, Schmitt, Kutas, & Münte, 2002; Schmitt, Rodriguez-Fornells, Kutas, & Münte, 2001; Schmitt, Schiltz, et al., 2001).

Aims and Structure of the Thesis

The aim of the present study is to investigate the temporal characteristics of the retrieval of semantic and syntactic word properties in language comprehension. In particular, an attempt is made to assess the retrieval order of grammatical gender and semantic category information, using the LRP and the N2 effect. The flexibility of this order is then explored by introducing primes that influence the retrieval of grammatical gender. Chapter 2 reports an experiment that employs the two-choice go/nogo task in combination with EEG recordings to establish the retrieval order of grammatical gender and semantic category for written words appearing without context. Chapter 3 focuses on the retrieval of grammatical gender. In order to examine whether gender retrieval can be speeded up by context, nouns are presented in gender congruent and gender incongruent prime-target pairs and reaction times for gender decisions are measured. In chapter 4, the gender congruency manipulation is transferred to another ERP experiment with the two-choice go/nogo task. While altering the time course of gender retrieval through primes, the order relative to semantic category retrieval is assessed again. In this way, the flexibility of the retrieval order established in chapter 2 is put to the test. Chapter 2 is accepted for publication, while chapters 3 and 4 are under submission as separate manuscripts. Finally, chapter 5 offers a summary and general discussion of the main findings in this thesis.

References

Abdel Rahman, R., & Sommer, W. (2003). Does phonological encoding in speech production always follow the retrieval of semantic knowledge? Electrophysiological evidence for parallel processing. *Cognitive Brain Research, 16,* 372-382.

Abdel Rahman, R., Van Turennout, M., & Levelt, W.J.M. (2003). Phonological encoding is not contingent on semantic feature retrieval: An electrophysiological study on object naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*, 850-860.

American Electroencephalographic Society (1991). Guidelines for standard electrode position nomenclature. *Journal of Clinical Neurophysiology, 8,* 200-202.

Branigan, H.P., Pickering, M.J., & Cleland, A.A. (2000). Syntactic co-ordination in dialogue. *Cognition, 75*, B13-B25.

Bock, K., & Griffin, Z.M. (2000). Producing words: How mind meets mouth. In L. Wheeldon (Ed.), *Aspects of language production* (pp. 7-47). Hove: Psychology Press.

Caramazza, A. (1997). How many levels of processing are there in lexical access? *Cognitive Neuropsychology, 14,* 177-208.

Coles, M.G.H. (1989). Modern mind-brain reading: Psychophysiology, physiology, and cognition. *Psychophysiology, 26*, 251-269.

Coles, M.G.H., & Rugg, M.D. (1995). Event-related brain potentials: An introduction. In M.D. Rugg & M.G.H. Coles (Eds.), *Electrophysiology of mind* (pp. 1-26). Oxford: Oxford University Press.

Collins, A.M., & Loftus, E.F. (1975). A spreading activation theory of semantic representation. *Psychological Review, 82*, 407-428.

Corbett, G.G. (1991). *Gender*. Cambridge: Cambridge University Press.

Cutler, A., & Clifton, C. Jr. (1999). Comprehending spoken language: A blueprint of the reader. In C.M. Brown & P. Hagoort (Eds.), *The neurocognition of language* (pp. 123-166). Oxford: Oxford University Press.

Dell, G.S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review, 93*, 283-321.

De Jong, R., Wierda, M., Mulder, G., & Mulder, L.J.M. (1988). Use of partial stimulus information in response processing. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 682-692.

Donchin, E., Ritter, W., & McCallum, C. (1978). Cognitive psychophysiology: The endogenous components of the ERP. In E. Callaway, P. Tueting, S.H. Koslow (Eds.), *Brain event-related potenials in man* (pp. 349-411). New York: Academic.

Donkers, F.C.L. & Van Boxtel, G.J.M. (2004). The N2 in go/no-go tasks reflects conflict monitoring not response inhibition. *Brain and Cognition, 56*, 165-176.

Eimer, M. (1993). Effects of attention and stimulus probability on ERPs in a go/nogo task. *Biological Psychology, 35,* 123-138.

Eimer, M. (1998). The lateralized readiness potential as an on-line measure of central response activation processes. *Behavior Research Methods, Instruments, & Computers, 30,* 146-156.

Elman, J.L. (2004). An alternative view of the mental lexicon. *Trends in Cognitive Sciences, 8*, 301-306.

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (1999). ERP components in go/nogo tasks and their relation to inhibition. *Acta Psychologica, 101,* 267-291.

Forster, K.I. (1979). Levels of processing and the structure of the language processor. In W.E. Cooper & E.C.T. Walker (Eds.), *Sentence processing: Psycholinguistic studies presented to Merrill Garrett* (pp.27-85). Hillsdale, NJ: Erlbaum.

Frazier, L. (1989). Against lexical generation of syntax. In W.D. Marslen-Wilson (Ed.), *Lexical representation and process* (pp. 505-528). Cambridge, MA: MIT Press.

Friederici, A.D. (1995). The time course of syntactic activation during language processing: A model based on neuropsychological and neurophysiological data. *Brain and Language, 50,* 259-281.

Friederici, A.D. (2002). Towards a neural basis of auditory sentence processing. *Trends in Cognitive Sciences, 6,* 78-84.

Gemba, H., & Sasaki, K. (1989). Potential related to no-go reaction of go/no-go hand movement task with color discrimination in human. *Neuroscience Letters, 101,* 263-268.

Harley, T.A. (1993). Phonological activation of semantic competitors during lexical access in speech production. *Language and Cognitive Processes, 8,* 291-309.

Jodo, E., & Kayama, Y. (1992). Relation of a negative ERP component to response inhibition in a go/nogo task. *Electroencephalography and Clinical Neurophysiology, 82,* 477-482.

Kempen, G., & Hoenkamp, E. (1987). An incremental procedural grammar for sentence formulation. *Cognitive Science, 11*, 201-258.

Kok, A. (1986). Effects of degradation of visual stimuli on components of the event-related potential (ERP) in go/nogo reaction tasks. *Biological Psychology, 23,* 21-38.

Komatsu, L.K. (1992). Recent views of conceptual structure. *Psychological Bulletin, 112*, 500-526.

Kornhuber, H.H., & Deecke, L. (1965). Hirnpotentialänderungen bei Willkürbewegungen und passiven Bewegungen des Menschen: Bereitschaftspotential und reafferente Potentiale [Brain potential changes associated with voluntary and passive movements in humans: Readiness potential and reafferent potentials]. *Pflügers Archive, 284,* 1-17.

Levelt, W.J.M. (1989). *Speaking: From intention to articulation*.Cambridge, MA: MIT Press

Levelt, W.J.M., Roelofs, A., & Meyer, A.S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences, 22,* 1-75.

MacDonald, M.C., Pearlmutter, N.J., & Seidenberg, M.S. (1994). Lexical nature of syntactic ambiguity resolution. *Psychological Review, 101,* 676-703.

Miller, J., & Hackley, S.A. (1992). Electrophysiological evidence for temporal overlap among contingent mental processes. *Journal of Experimental Psychology: General, 121,* 195-209.

Nieuwenhuis, S., Yeung, N., Van den Wildenberg, W., & Ridderinkhof, K.R. (2003). Electrophysiological correlates of anterior cingulate function in a go/nogo task: Effects of response conflict and trial-type frequency. *Cognitive, Affective, & Behavioral Neuroscience, 3*, 17-26.

Osman, A., Bashore, T.R., Coles, M.G.H., Donchin, E., & Meyer, D.E. (1992). On the transmission of partial information: Inferences from movement-related brain potentials. *Journal of Experimental Psychology: Human Perception and Perception, 18,* 217-232.

Perfetti, C. (1999). Comprehending written language: A blueprint of the reader. In C.M. Brown & P. Hagoort (Eds.), *The neurocognition of language* (pp. 167-208). Oxford: Oxford University Press.

Pfefferbaum, A., Ford, J.M., Weller, B.J., & Kopell B.S. (1985). ERPs to response production and inhibition. *Electroencephalography and Clinical Neurophysiology, 60,* 423-434.

Pfurtscheller, G., & Lopes da Silva, F.H. (1999). Event-related EEG/MEG synchronization and desynchronization: Basic principles. *Clinical Neurophysiology, 110*, 1842-1857.

Picton, T.W., Lins, O.G., & Scherg, M. (1995). The recording and analysis of event-related potentials. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology, Vol. 10* (pp. 3-73). New York: Elsevier.

Plaut, D.C., & Shallice, T. (1993). Deep dyslexia: A case study of connectionist neuropsychology. *Cognitive Neuropsychology, 10*, 377-500.

Rodriguez-Fornells, A., Schmitt, B.M., Kutas, M., & Münte, T.F. (2002). Electrophysiological estimates of the time course of semantic and phonological encoding during listening and naming. *Neuropsychologia, 40,* 778-787.

Rugg, M.D., & Coles, M.G.H. (1995). The ERP and cognitive psychology: Conceptual issues. In M.D. Rugg & M.G.H. Coles (Eds.), *Electrophysiology of mind* (pp. 27-39). Oxford: Oxford University Press.

Sasaki, K., Gemba, H., Nambu, A., & Matsuzaki, R. (1993). No-go activity in the frontal association cortex of human subjects. *Neuroscience Research, 18*, 249-252.

Sasaki, K., Gemba, H., & Tsujimoto, T. (1989). Suppression of visually initiated hand movement by stimulation of the prefrontal cortex in the monkey. *Brain Research, 495*, 100-107.

Schmitt, B.M., Münte, T.F., & Kutas, M. (2000). Electrophysiological estimates of the time course of semantic and phonological encoding during implicit picture naming. *Psychophysiology, 37,* 473-484.

Schmitt, B.M, Rodriguez-Fornells, A., Kutas, M., & Münte, T.F. (2001). Electrophysiological estimates of semantic and syntactic information access during tacit picture naming and listening to words. *Neuroscience Research, 41,* 293-298.

Schmitt, B.M., Schiltz, K., Zaake, W., Kutas, M., & Münte, T.F. (2001). An electrophysiological analysis of the time course of conceptual and syntactic encoding during tacit picture naming. *Journal of Cognitive Neuroscience, 13*, 510-522.

Simson, R., Vaughan, H.G., & Ritter, W. (1977). The scalp topography of potentials in auditory and visual go/nogo tasks. *Electroencephalography and Clinical Neurophysiology, 43,* 864-875.

Smid, H.G.O.M., Mulder, G., Mulder, L.J.M., & Brands, G.J. (1992). A psychophysiological study of the use of partial information in stimulus-response translation. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 1101-1119.

Stemberger, J.P. (1985). An interactive activation model of language production. In A.W. Ellis (Ed.), *Progress in the psychology of language, Vol. 1* (pp. 143-186). London: Erlbaum.

Thorpe, S., Fize, D., & Marlot, C. (1996). Speed of processing in the human visual system. *Nature, 381,* 520-522.

Trueswell, J.C., & Tanenhaus, M.K. (1994). Toward a constraint-based lexicalist approach to syntactic ambiguity resolution. In C. Clifton, L. Frazier, & K. Rayner (Eds.), *Perspectives on sentence processing* (pp. 155-179). Hillsdale, NJ: Erlbaum.

Urbach, T.P., & Kutas, M. (2002). The intractability of scaling scalp distributions to infer neuroelectric sources. *Psychophysiology, 39*, 791-808.

Van Boxtel, G.J.M., Van der Molen, M.W., Jennings, J.R., & Brunia, C.H.M. (2001). A psychophysiological analysis of inhibitory motor control in the stop-signal paradigm. *Biological Psychology, 58*, 229-262.

Van Turennout, M., Hagoort, P., & Brown, C.M. (1997). Electrophysiological evidence on the time course of semantic and phonological processes in speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 787-806.

Van Turennout, M., Hagoort, P., & Brown, C.M. (1998). Brain activity during speaking: From syntax to phonology in 40 milliseconds. *Science, 280,* 572-574.

Vaughan, H.G. Jr., Costa, L.D., & Ritter, W. (1968). Topography of the human motor potential. *Electroencephalography & Clinical Neurophysiology, 25*, 1-10.

ACCESS TO LEXICAL INFORMATION IN LANGUAGE COMPREHENSION: SEMANTICS BEFORE SYNTAX

Chapter 2

Oliver Müller and Peter Hagoort (in press). *Journal of Cognitive Neuroscience*.*

Abstract

The recognition of a word makes available its semantic and syntactic properties. Using electrophysiological recordings, we investigated whether one set of these properties is available earlier than the other set. Dutch participants saw nouns on a computer screen and performed push-button responses: In one task grammatical gender determined response hand (left/right) and semantic category determined response execution (go/nogo). In the other task response hand depended on semantic category while response execution depended on gender. During the latter task response preparation occurred on nogo-trials, as measured by the lateralized readiness potential: Semantic information was used for response preparation before gender information inhibited this process. Furthermore, an inhibition-related N2 effect occurred earlier for inhibition by semantics than for inhibition by gender. In summary, electrophysiological measures of both response preparation and inhibition indicated that the semantic word property was available earlier than the syntactic word property when participants read single words.

* This chapter is a slightly adapted version of the manuscript to be published.

Introduction

Reading a text is an enterprise that begins with the visual perception of lines and dots and ends with some notion about the meaning of the text. One major step in this process is word recognition, that is, identifying a configuration of script symbols as a particular word. In the course of word recognition, lexical knowledge – the meaning and syntactic properties of words – becomes available. This forms the input to sentence processing, which assembles the information associated with individual words into larger syntactic and semantic structures. The access to semantic and syntactic word properties is an important transition point. By proceeding from the word as perceptual unit to the word as carrier of semantic and syntactic information, it becomes possible to (re)construct a meaningful message from a string of words. Word meanings form as it were the building blocks of overall text meaning, whereas syntactic word properties give information about how words relate to each other. The grammatical gender of nouns is a syntactic word property, which exists in a wide variety of languages, such as Dutch, Italian, Hebrew, and Swahili (cf. Corbett, 1991). Depending on the language at hand, grammatical gender of a noun can determine the form of articles, adjectives, pronouns, and other kind of words, a phenomenon called gender agreement. The Dutch language knows two grammatical genders, labeled common and neuter gender. In Dutch, the most prominent instance of gender agreement concerns the form of the singular definite article. For common gender nouns, the article takes the form *de* and for neuter gender nouns, it takes the form *het*. Translating ***The*** *farmer caught* **the** *lamb* into Dutch results in ***De*** *boer pakte* **het** *lam*, since *boer* is of common gender and *lam* is of neuter gender.

Despite the importance of the access to semantic and syntactic word properties, little is known about the time course of the involved retrieval operations. In this article, we want to focus on the relative time course regarding the availability of semantic and syntactic properties of single words. Is lexico-semantic information available before lexico-syntactic information, or is the opposite true? While numerous studies investigated the impact of semantic and syntactic context on word recognition, they focused on whether and how this might occur, often treating semantic and syntactic contexts separately (Balota, 1994; Friederici & Jacobsen, 1999). And although the field of sentence processing figures a controversy about when syntactic and semantic information are used in parsing (e.g., Frazier, 1989; Friederici, 2002; MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell & Tanenhaus, 1994), an extrapolation from sentence processing to retrieval of semantic and syntactic word properties during word recognition seems not straightforward.

In speech production research, clear assumptions about the time course of access exist. A wide range of models assumes that word properties are represented in an ordered set of layers, with activation spreading from a semantic layer to a syntactic layer (the so-called lemma layer) and from there to a phonological layer (cf. Levelt, 1999; but see Caramazza, 1997). Thus, semantic and syntactic aspects of words are represented in separate layers, with semantic word properties receiving activation before syntactic word properties. [1] Levelt, Roelofs, and Meyer (1999) have proposed that language comprehension and production share the semantic and the lemma level: “the perceptual and production networks coincide from the lemma level upwards” (p. 7). One can assume that the direction of processing in comprehension is reversed in relation to that in speech production. While processing in comprehension starts with a perceived word shape and heads towards a conceptual understanding, in production it starts with a conceptual intention and heads towards word shape. Regarding the reading of words, one would then expect syntactic word properties to be available earlier than semantic properties.

Here, we investigated the time course of syntactic and semantic activation in single word reading by means of specific brain responses, the so-called lateralized readiness potential (LRP) and the inhibition-related N2 response, taking advantage of the temporal resolution of a few milliseconds characteristic of event-related brain potentials (ERPs). The LRP is regarded an index of specific response preparation and is derived from the readiness potential (RP), which can be observed before voluntary hand movements (Kornhuber & Deecke, 1965). Kutas and Donchin (1980) showed that the RP for unimanual responses is largest at electrodes above the motor cortex contralateral to the moving hand, corresponding to the functional neuroanatomy of movement preparation. The LRP represents the average lateralization of movement-related activity and indicates that response preparation for a particular hand takes place (De Jong, Wierda, Mulder, & Mulder, 1988; Coles, Gratton, & Donchin, 1988). In combination with the two-choice go/nogo paradigm the LRP has proven useful to investigate the temporal dissociation of different kinds of information (Miller & Hackley, 1992; Osman, Bashore, Coles, Donchin, & Meyer, 1992).Van Turennout, Hagoort, and Brown (1997) pioneered in applying this paradigm to the investigation of time course issues in language processing. They studied the access to semantic and phonological word properties in speech production. Participants performed a picture-naming task in Dutch. On some trials they additionally had to perform a two-choice go/nogo task: The semantic category of the pictures (animal/object) determined whether to give a response with the left or right hand, while the last phoneme of the picture name determined whether a response should be actually executed or not (go/nogo). As semantic information would become available, the movement of a particular hand could be prepared. That in turn should appear as lateralized motor activity, that is, an LRP. Most interestingly, Van Turennout et al. found temporary LRP activity in the nogo-condition, which declined again without triggering an overt response. Thus, semantic information instructed specific response preparation for some time before phonological information stopped this process. This suggests that semantics is available before phonology in speech production. However, Smid, Mulder, Mulder,

1. Activation flow between the concept and lemma level is assumed to be cascaded and bidirectional, so that periods of activation in the two layers may overlap.

and Brands (1992) demonstrated that participants can exert strategic control about the order in which they use stimulus information in the two-choice go/nogo paradigm. In particular, participants might prefer to use the response hand information first and the go/nogo information later, in order to start movement preparation as soon as possible and gain faster responses on go-trials. This could have been an alternative explanation of the nogo-LRP activity in Van Turennout et al.'s experiment, without reference to some intrinsic processing order. However, this strategic account would also predict a nogo-LRP under reversed instructions, with phonology determining response hand and semantics determining the go/nogo decision. Van Turennout et al. conducted a second experiment with exactly these instructions, but found no LRP for nogo-trials, ruling out the strategic account.

Schmitt, Münte, and Kutas (2000) introduced another ERP component for monitoring the time course of language processing, the inhibition-related N2. In experiments with a go/nogo task, the ERP for nogo-trials displays a negative peak of several microvolts with a frontocentral distribution (Gemba & Sasaki, 1989; Kok, 1986; Pfefferbaum, Ford, Weller, & Kopell, 1985; Simson, Vaughan, & Ritter, 1977; Thorpe, Fize, & Marlot, 1996). It is widely assumed that the nogo-related negativity reflects response inhibition (Eimer, 1993; Falkenstein, Hoormann, & Hohnsbein, 1999; Jodo & Kayama, 1992; Kok, 1986). Schmitt et al. (2000) employed the inhibition-related N2 in a study that replicated Van Turennout et al. (1997) in German. Semantics and phonology of picture names again determined response hand and the go/nogo decision. When semantics controlled the inhibition-relevant go/nogo decision, the N2 effect occurred significantly earlier than when phonology did. This again provided evidence for the earlier availability of semantic information relative to phonological information. The LRP analysis corroborated the N2 finding, paralleling the results of Van Turennout et al.

Schmitt, Rodriguez-Fornells, Kutas, and Münte (2001) applied the two-choice go/nogo paradigm to semantic and syntactic access, during both speech production and auditory language comprehension. They employed an animal/object categorization tapping into semantic processing and a (German) grammatical gender categorization tapping into syntactic processing. The speech production experiment used picture stimuli, while the auditory comprehension experiment used sound recordings of the picture names. In each experiment, semantic category and gender were alternately mapped onto response hand and the go/nogo decision. In the speech production experiment, the N2 occurred earlier when semantics determined response inhibition than when gender did. This concurs with the assumptions of speech production theories. It is furthermore supported by a behavioral picture-naming study that manipulated the semantic relatedness and gender congruency of distractor words at several SOAs (Schriefers & Teruel, 2000). Effects of semantic relatedness occurred at earlier SOAs than effects of gender congruency. Schmitt, Rodriguez-Fornells et al.'s second ERP experiment, with auditorily presented words, showed the same retrieval order as for pictures, that is, an earlier N2 effect for semantics than for gender.

This is actually the opposite outcome one expects under the assumption that speech production and language comprehension share the representations of semantic and syntactic word properties, but access them in a reversed order.

However, one might hesitate to generalize time course findings from an experiment with spoken words to the processing of written words. The spoken word form is extended in time and information from the unfolding speech signal is assumed to be continuously mapped onto lexical representations (Marslen-Wilson, 1987; McClelland & Elman, 1986; Norris, 1994). In contrast, the written word form provides all perceptual information at once and, at least in principle, information from all letter positions could be processed in parallel (cf. Radeau, Morais, Mousty, Saerens, & Bertelson, 1992; Rastle & Coltheart, 1999; Zorzi, 2000). Should cues to different kinds of information (e.g., semantic and syntactic) be located at separate positions of a word form, this would entail in the auditory modality that these cues would appear at different points in time. That is, information extractable from an early position would have a temporal advantage over information at a late position. Allopenna, Magnuson, and Tanenhaus (1998) have provided evidence that listeners actually pick up information in the order in which it becomes available in the speech signal. They used spoken stimuli such as *beaker*, which is consistent with *beetle* in its initial portion and with *speaker* in its later portion. Both these partially consistent words showed signs of activation in a continuous eye movement measure, but the onset-related *beetle* (and *beaker* itself) showed an earlier effect than the rhyming word *speaker*. Thus, the effect indicating the word's activation mirrored the time course of the acoustic evidence for that word. A study by Van den Brink and Hagoort (2004; also see Hagoort, 2003) indicates that also semantic and syntactic information of a spoken word are extracted in the order in which corresponding cues occur in the speech signal. In an ERP experiment, they presented sentences where the critical word was either semantically appropriate or inappropriate and the inappropriate word additionally violated lexical category constraints – being a verb although a noun was required. The semantic violation could be detected relatively early, as the phonological form of the inappropriate item deviated from the most expected word. Concerning the syntactic violation, the incoming speech signal was consistent with the inappropriate word being a noun until the last syllable, which was a past tense inflectional suffix identifying the word as a verb. This was deliberately different from earlier auditory studies, where a prefix had marked the lexical category violation right at word onset (e.g., Friederici, Pfeifer, & Hahne, 1993; Hahne & Jescheniak, 2001). In the latter experiments lexical category violations elicited a left anterior negativity earlier than the usual timing of the semantic N400 effect (cf. Kutas & Van Petten, 1994). However, this order was reversed in the Van den Brink and Hagoort study where lexical category information occurred late in the word. Thus, it seems that also the availability of semantic and syntactic information depends on their temporal position within the spoken word form.

The interpretation of time course findings obtained with spoken words should therefore take into account that cues to semantic and syntactic information could have occurred in temporally different stretches of words and that such signal-related availability could have biased the findings. An experiment with written words, where all perceptual information is delivered simultaneously, would not be prone to such an influence and might lead to different time course results. Therefore, we decided to conduct an experiment with written word forms to investigate the time course with which semantic and syntactic information become available in language comprehension.

Participants performed a two-choice go/nogo task on single Dutch nouns, with a semantic category decision and a grammatical gender decision probing the access to semantic and syntactic word properties. One half of the participants received instructions in which grammatical gender determined response hand (left/right) and semantic category determined the go/nogo decision. The other half received instructions that mapped semantic category on response hand and grammatical gender on the go/nogo decision (see table 2-1 for examples).

Table 2-1. *Example of the Mapping of the Stimulus Dimensions Grammatical Gender and Semantic Category onto the Response Dimensions Hand and Response Execution, with Dutch Example Words (English Translation in Brackets)*

Task: hand = semantics, go/nogo = gender	*common* = go	*neuter* = nogo
building = left hand	schuur (barn)	hotel (hotel)
consumable = right hand	melk (milk)	zout (salt)

Task: hand = gender, go/nogo = semantics	*common* = left hand	*neuter* = right hand
building = go	schuur (barn)	hotel (hotel)
consumable = nogo	melk (milk)	zout (salt)

Method

Participants

Thirty-two native speakers of Dutch (27 female) participated in the experiment, with age being on average 21.3 years and ranging from 17 to 27 years. All participants were right-handed and had normal or corrected-to-normal vision. None of them suffered from a neurological impairment, had experienced a neurological trauma, or was taking neuroleptics. The participants received payment for taking part in the experiment.

Materials

Words from the eight semantic categories building, consumable (food and beverages), landscape formation, animal, part of a house, clothing, weapon, and body part served as stimuli. For the semantic decision task, we constructed eight different category pairings to allow for binary decisions (see table 2-2). Each category contributed common and neuter gender words. In order to achieve an approximately equal number of common and neuter gender words within each semantic category, diminutives were included in the item set. In Dutch, diminutives are formed by attaching a suffix to a noun and automatically carry neuter gender, regardless of the gender of the base word (several allomorphs are used, depending on the phonological form of the base word, but all end in *-je*, cf. Donaldson, 1987). Each category contained 12 or 14 monomorphemic common gender targets and usually an equal number of neuter gender targets (never less than 45% neuter gender nouns, see table 2-3 for details). At least half of the neuter gender targets within a category were monomorphemic and had intrinsic neuter gender, while the rest were diminutives. Within a category pairing,

Table 2-2. *First and Second Set of Category Pairings for the Semantic Decision*

Set 1			
	1. building	vs.	consumable
	2. building	vs.	animal
	3. landscape formation	vs.	consumable
	4. landscape formation	vs.	animal
Set 2			
	5. part of a house	vs.	clothing
	6. part of a house	vs.	body part
	7. weapon	vs.	clothing
	8. weapon	vs.	body part

Table 2-3. *Statistics of Item Set, Split up for Semantic Categories and Common (com) and Neuter (neu) Gender Nouns*

semantic category	*number of items*		*length in letters mean (min-max)*		*lemma frequency* [a]	
	com	intrinsic neu + dim [b]	com	neu [c]	com	neu [c]
building	14	7 + 7	5.4 (3-8)	6.1 (3-8)	36.1	38.8
consumable	14	7 + 7	5.0 (3-8)	5.4 (4-8)	36.2	28.1
landscape formation	14	7 + 6	5.8 (3-8)	5.5 (3-7)	27.9	22.5
animal	14	7 + 7	5.4 (3-8)	5.7 (4-8)	18.2	30.2
part of a house	12	6 + 4	4.9 (3-7)	5.9 (3-8)	96.7	48.9
clothing	12	6 + 6	5.2 (3-7)	5.8 (4-8)	15.6	13.9
weapon	12	6 + 4	5.2 (3-8)	6.0 (3-8)	20.3	16.9
body part	12	6 + 6	4.8 (3-8)	5.3 (3-8)	53.3	133.1
sum/average [d]	104	52 + 47	5.2	5.7	37.4	41.1

[a] mean lemma frequency per million, CELEX Dutch database (1990)
[b] separate counts for intrinsically neuter nouns and diminutives
[c] collapsed over intrinsically neuter nouns and diminutives
[d] sum: columns *number of items*; average: columns *length in letters* and *lemma frequency*

the distributions of word length in letters and lemma frequency substantially overlapped for the two semantic categories and the two gender classes (see table 2-3). Six additional items from each category (three from each gender class) served as practice trials before experimental blocks and another extra item served as warm-up trial in the experimental blocks. For a practice block at the beginning of a session, we used words from the categories musical instrument and plant.

Procedure

Participants were seated in a dimly lit sound-attenuating booth, facing a computer screen. They rested their arms on the arm rests of the chair and held the left and right index finger on response buttons, inserted in the arm rests. A trial started with the presentation of a fixation cross in the middle of the screen for 2000 ms. Next the screen turned blank for 1000 ms and then a word appeared on the screen for 1000 ms. After disappearance of the word the screen stayed blank for 2050 ms and a new trial began. Words were presented in white lowercase Arial letters against dark background. Viewing distance was approximately 100 cm, the visual angle for the longest word was about 2.4° horizontally and 0.4° vertically. Participants performed a two-choice go/nogo task. One half of the participants received instructions in which grammatical gender determined response hand (left/right) and semantic category determined response execution (go/nogo). The other half received instructions that mapped semantic category on response hand and grammatical gender on response execution (see table 2-1 for examples). Participants were asked to keep their arms relaxed and not to blink or move their eyes, except for the period when the fixation cross was on the screen.

There was a practice block comprising 96 trials at the beginning of each session, followed by eight experimental blocks (table 2-2). Each block started with an instruction given via the screen, indicating for which class of words participants were supposed to press the left or right button and for which class of words the movement had to be executed or not. Examples were provided for all response possibilities (left-go, left-nogo, right-go, right-nogo). A series of 12 practice trials followed the instruction. Experimental blocks contained 46 to 56 stimuli, depending on the semantic categories involved. Within blocks, items occurred in a pseudo-randomized order, with the restriction that maximally three items of a given grammatical gender or semantic category would appear in succession. No more than two participants received the same randomization. For a given participant, the mapping of grammatical gender onto response dimension (left/right or go/nogo) was the same for all blocks from the category pairings of set 1 (table 2-2) and the reversed mapping for all blocks from the category pairings of set 2. The response mapping of grammatical gender within these sets of category pairings was balanced across participants. The mapping of a semantic category onto response dimensions was constant for a given participant, while it was balanced across participants. The required response for an item stayed the same across repetition. The order of blocks was randomized with the following restrictions: After the first experimental block, a block from the opposite set of category pairings occurred, so that the grammatical gender mapping changed. Furthermore, blocks containing the same semantic category were separated by two blocks containing other semantic categories. This led to a ABBAABBA structure of block order, where A and B represent blocks from a particular set of category pairings.

Apparatus and Recordings

The EEG was recorded at 26 sites on the scalp, with reference to the left mastoid. These sites represent a selection of electrode slots in the Easy-Cap Montage No. 10 as provided by Falk Minow Services (for theta/phi coordinates see: Theta/phi-coordinates of equidistant montage no. 10, n.d.). The six midline sites with the numbers 35, 20, 2, 1, 14, and 43 correspond to the positions Fpz, AFz, FCz, Cz, Pz, and Oz of the 10%-system of the American Electroencephalographic Society (1991). The remaining electrodes were placed laterally over symmetrical positions: frontal (in pairs of corresponding electrodes: 49, 37; 50, 36; 33, 22; 34, 21), frontocentral (18, 10; 7, 3; 17, 11; 6, 4), and occipital (45, 41; 44, 42). We used the electrode pairs 18/10 and 7/3 in the computation of the LRP.[2] Electrode pair 18/10 was approximately 6 cm lateral and 3 cm anterior to Cz, while electrode pair 7/3 was approximately 3 cm lateral and 2 cm anterior to Cz. In order to control the quality of the left mastoid as neutral reference, an additional electrode was attached to the right mastoid, referenced to the left mastoid. A ground electrode was placed on the forehead. Blinks and vertical eye-movements were recorded bipolarly using electrodes situated above and below the left eye. Horizontal eye movements were monitored via a bipolar montage of electrodes positioned external to the left and right outer canthus of each eye. The EMG of the left and right forearm flexors was recorded bipolarly with electrodes placed following the recommendations of Lippold (1967). Ag/AgCl electrodes were used for all recordings. Electrode impedance was kept below 3kΩ for the EEG recording, below 5 kΩ for the electrooculogram (EOG) recording, and below 10 kΩ for the EMG recording. The signals were amplified by a Neuroscan SynAmp amplifier and data acquisition occurred via Scan 4.1 Software from Neuroscan. For all recordings, a time constant of 8s was set. The high-frequency cutoff was 30 Hz for EEG and EOG recordings and 100 Hz for the EMG recording. Digitization of the signals took place on-line with a sampling frequency of 500 Hz. Sampling started 150 ms before word onset and continued for an epoch of 2100 ms.

The 150 ms period before word onset served as baseline and its average voltage per trial and electrode was subtracted from the respective waveforms. Artifact control occurred for epochs from 150 ms before word onset until 1500 ms after word onset. The EMG was visually inspected and nogo-trials showing muscular activity as well as go-trials showing activity of the wrong response hand were discarded. In this way, low-level muscle activity on nogo-trials was excluded, which indicates incomplete inhibition and is an unwanted source of temporary LRP activity. Concerning the go-conditions, activation of both hands would reduce the movement-related lateralization and thereby corrupt the go-LRP. EOG and scalp electrodes were controlled for eye movement artifacts, amplifier blocking, and amplitudes exceeding 75 μV above or below baseline. Behavioral errors were coded for nogo-trials in which a push-button response was registered and for go-trials where the wrong push-button was pressed or no response was registered within 1500 ms after stimulus appearance. Trials showing eye movement or EEG artifacts were excluded from all analyses, whereas trials with behavioral errors were excluded from RT and ERP analyses. For each participant there were at least 35 trials left per response hand and go/nogo condition.

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2. We adopted the formula proposed by De Jong et al. (1988):

$$\text{LRP} = \text{Average}(L - R)_{\text{right hand}} - \text{Average}(L - R)_{\text{left hand}}$$

Where *L* and *R* represent electrodes seated above the left and right motor cortices, respectively. De Jong et al. refer to it as the corrected motor asymmetry, but the common label nowadays is LRP. This formula is equivalent to the proposal of Coles et al. (1988), with the exception that the latter results in a LRP of half the amplitude.

Results

The data analysis includes only words of common gender. About half of our neuter gender words were diminutives. They are marked by an orthographic suffix and automatically possess neuter gender in Dutch. In this way, *de kerk* (the church) can become *het kerkje*. Inclusion of the diminutives in the material had been necessary to arrive at an approximately equal amount of common and neuter gender words in each semantic category. Finding enough words with intrinsic neuter gender was complicated by the fact that Dutch shows a preponderance towards common gender, which makes up about three quarter of all nouns (cf. Van Berkum, 1996). Because of the orthographic marking diminutives are not suited to investigate lexical access to grammatical gender, and the number of intrinsically neuter gender items was insufficient for a separate analysis of their electrophysiological data.

Overt Responses

The RT for common gender words averaged across participants was 775 ms for the hand = semantics task (go/nogo = gender) and 796 ms for the hand = gender task (go/nogo = semantics). The difference between the two tasks did not reach significance in a t-test, with $t(30) = -1.1$, $SE = 19.8$, and $p = .291$.

Different types of error apply to go-trials (wrong response hand and timeout) and nogo-trials (any overt response). Therefore, we performed separate error analyses for the go- and nogo-conditions. The average error percentage on go-trials was 3.2 for the hand = semantics task (go/nogo = gender) and 5.4 in the hand = gender task (go/nogo = semantics). This was significant in a t-test, with $t(30) = -2.2$, $SE = .966$, and $p = .037$. For nogo-trials, the average error percentage was 0.7 in the hand = semantics task and 0.8 in the hand = gender task. The difference was not significant ($t(30) = -.2$, $SE = .430$, $p = .833$).

Lateralized Readiness Potential

We computed stimulus-locked LRPs for the hand = semantics task (go/nogo = gender) and the hand = gender task (go/nogo = semantics), separately for the go- and nogo-conditions. The reported results are based on waveforms which represent the average of LRPs from the electrode pairs 18/10 and 7/3. Inspection of participant and grand average waveforms had shown that they provided the biggest go-LRP amplitude. The averaging combined the LRP data from both electrodes into one dependent measure, so that activations consistently present at both electrodes were favored in the analysis. To test for correct preparatory motor activity in the LRP, we performed series of t-tests on voltage amplitude. First, moving averages of voltage were computed for the go- and nogo-conditions of both tasks, derived from all subject LRPs. Window width was 50 ms, with the first window starting at 6 ms and ending at 54 ms after stimulus onset, so that its center was at 30 ms. The next window was shifted in time by 10 ms, having its center at 40 ms and so forth. The last window had its center at 1000 ms after stimulus onset. For every window, a one-tailed t-test against zero was performed on the moving averages. If five consecutive windows with negative voltage had a p value $< .05$, we assumed that a meaningful deviation from baseline had occurred, that is, some correct preparatory activation had been present. The center of the first significant window counted as onset latency of LRP activity.

Grand average LRPs for the go- and nogo-condition of the hand = semantics task (go/nogo = gender) are shown in figure 2-1a. Go- and nogo-waveform showed no significant activity during the first 400 ms. At 440 ms, the go-LRP started to deviate significantly from baseline ($-11.8 < t(15) < -1.7$, $.001 < p < .047$). Significant nogo-activity occurred shortly later, from 480 to 530 ms ($-2.6 < t(15) < -1.7$, $.012 < p < .05$) and from 570 to 620 ms ($-2.5 < t(15) < -1.7$, $.014 < p < .043$). Go- and nogo-waveform ran parallel during the ascent from baseline, while later the go-LRP continued to increase and the nogo-LRP entered a gradual decline to baseline. We compared the two waveforms directly with a series of paired samples t-tests on the moving averages, which yielded no significantly different region until 510 ms (from then on: $-7.7 < t(15) < -2.1$, $.001 < p < .05$; criterion of five consecutive significant windows). For the hand = gender task (go/nogo = semantics), grand average LRPs are presented in figure 2-1b. The go-LRP displayed some early significant activity from 260 to 310 ms ($-2.6 < t(15) < -1.9$, $.011 < p < .034$), while the main negativity started to deviate significantly from baseline at 400 ms ($-8.1 < t(15) < -1.7$, $.001 < p < .045$). In the nogo-condition, there was significant activity from 140 to 260 ms ($-3.7 < t(15) < -1.8$, $.001 < p < .039$). No other regions showed significant deviations from baseline. Additionally, we tested whether the onset of the go-LRP main negativities differed between tasks. We took the moving averages of both go-LRPs and compared them through a series of two-tailed independent samples t-tests. The go-LRPs differed significantly only between 260 and 310 ms ($2.3 > t(30) > 2.1$, $.029 < p < .049$). From 340 ms on, all p values > 10. [3]

3. We also applied a jackknifing procedure, which estimates ERP onset latencies based on grand averages and uses a conventional ANOVA, plus some simple adjustment of the F ratio (Ulrich & Miller, 2001). We set an absolute onset criterion of -0.4 µV, surveying the period from 350 to 600 ms. The estimated onset latencies were similar to the ones from the t-test procedure, 427 ms for the hand = semantics task and 399 for the hand = gender task. This difference was not significant in a between-subject ANOVA with the factor Task (adjusted $F(1,30) < 1$). Furthermore, 14 participants had additionally performed a second task for exploratory purposes. Half of them had started with the semantics = hand task and then performed the gender = hand task, while the others had followed the opposite task order (only first task data had entered the between-subjects analysis reported above). For these counterbalanced within-subjects data, serial t-tests against baseline resulted in a go-LRP onset latency of 450 ms for the semantics = hand task and 470 ms for the gender = hand task. A direct comparison of the go-waveforms with serial t-tests and the jackknife procedure showed no significant onset difference.

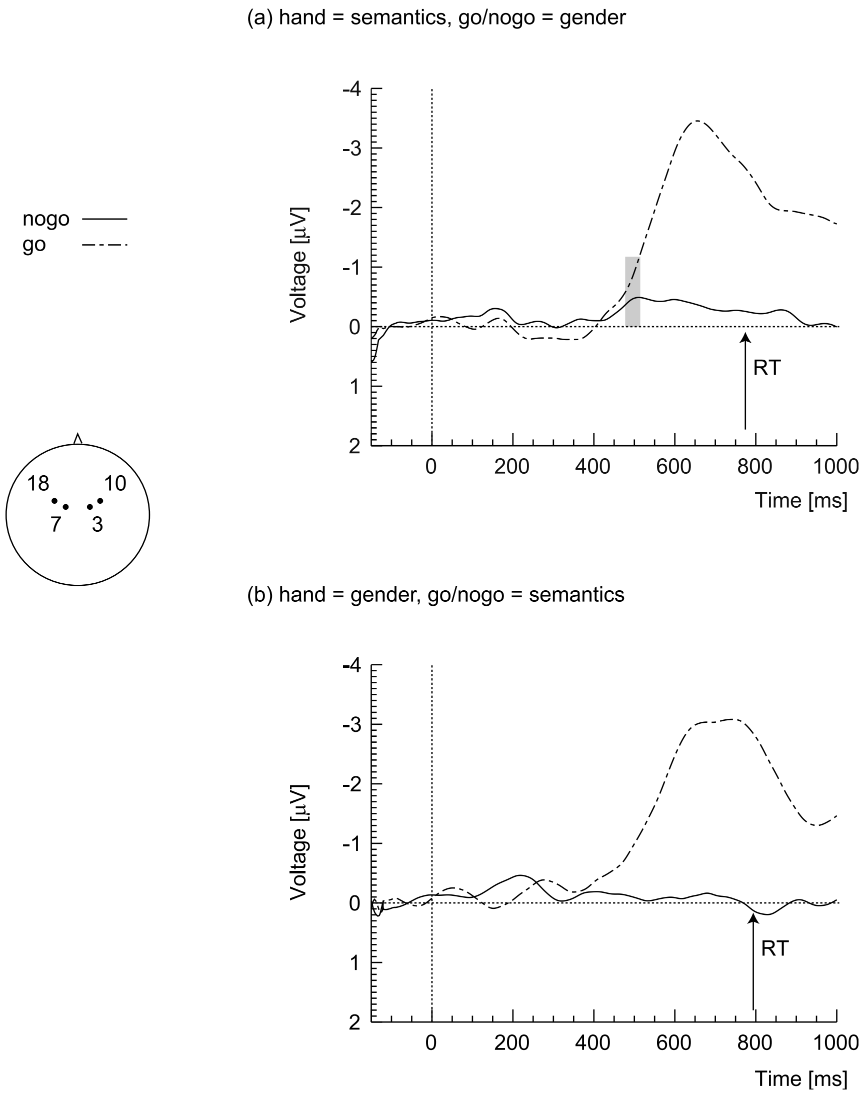

Figure 2-1. *LRP grand averages for go- and nogo-trials, averaged across the electrode pairs 18/10 and 7/3. Arrows mark the average RT for the go-conditions of the two tasks. (a) Task hand = semantics, go/nogo = gender. The grey rectangle indicates the period from the onset of nogo-activity (480ms) to the divergence of go- and nogo-waveform (510ms). (b) Task hand = gender, go/nogo = semantics.*

N2 inhibition-related effect

We computed participant and grand averages for the go- and nogo-conditions of the go/nogo = gender and the go/nogo = semantics task. In both tasks, the go- and nogo-waveforms developed in parallel during the first 250 ms. At frontal electrodes, a negative peak around 125 ms was followed by a positive peak around 175 ms after stimulus presentation (see figure 2-2, a and b). Then a sustained negativity with a peak around 450 ms appeared for nogo-conditions, diverging from the go-waveform at roughly 350 ms for the gender=go/nogo task and at 250 ms for the semantics=go/nogo task. To obtain a net inhibition effect, we subtracted the go-conditions from the nogo-conditions. The subtraction waveforms displayed a negative effect, comparable to the N2 effects reported in earlier ERP studies using inhibition paradigms (figure 2-2c). The most noticeable difference between the N2 effects of the two tasks was that the effect for the go/nogo = semantics task seemed to occur earlier than the effect for the go/nogo = gender task.

We determined the peak latency of the N2 effect by searching for the largest negative voltage value within a time window from 300 to 700 ms after stimulus onset, separately for all ten frontal electrodes. An ANOVA was performed on the peak latencies, with Task as between-subjects factor and Electrode as within-subjects factor.[4] The peak latencies across electrodes and participants were 454 ms for the go/nogo = semantics task and 554 for the go/nogo = gender task. The corresponding main effect of Task was significant, with $F(1,30) = 15.0$, $MSE = 53771.9$, and $p = .001$. However, neither the main effect of Electrode ($F(9,270) = 1.6$, $MSE = 3523.9$, $p = .179$, $\varepsilon = .492$) nor the interaction between Task and Electrode reached significance ($F(9,270) = 1.3$, $MSE = 3523.9$, $p = .270$, $\varepsilon = .492$).

Discussion

In this study, we examined the temporal order, in which semantic category and grammatical gender information become available during the reading of single Dutch words. Two groups of participants performed different two-choice go/nogo tasks, both combining a semantic with a gender classification. For the group carrying out the hand = semantics task (go/nogo = gender), we found some temporary LRP activity in the nogo-condition from 480 to 530 ms. This occurred in parallel with the go-LRP of the same task, which had an onset around 440 ms. The group performing the hand = gender task (go/nogo = semantics) showed early LRP activity, from 140 to 260 ms in the nogo-condition and from 260 to 310 ms in the go-condition. This was well before onset of the main go-LRP in that task, which

4. We performed univariate F-tests in our analyses and corrected violations of sphericity for repeated measures factors by adjusting *df*s with the Greenhouse-Geisser epsilon. When applicable, we report the uncorrected *df*s and *MSE*, followed by the corrected p value and the ε value.

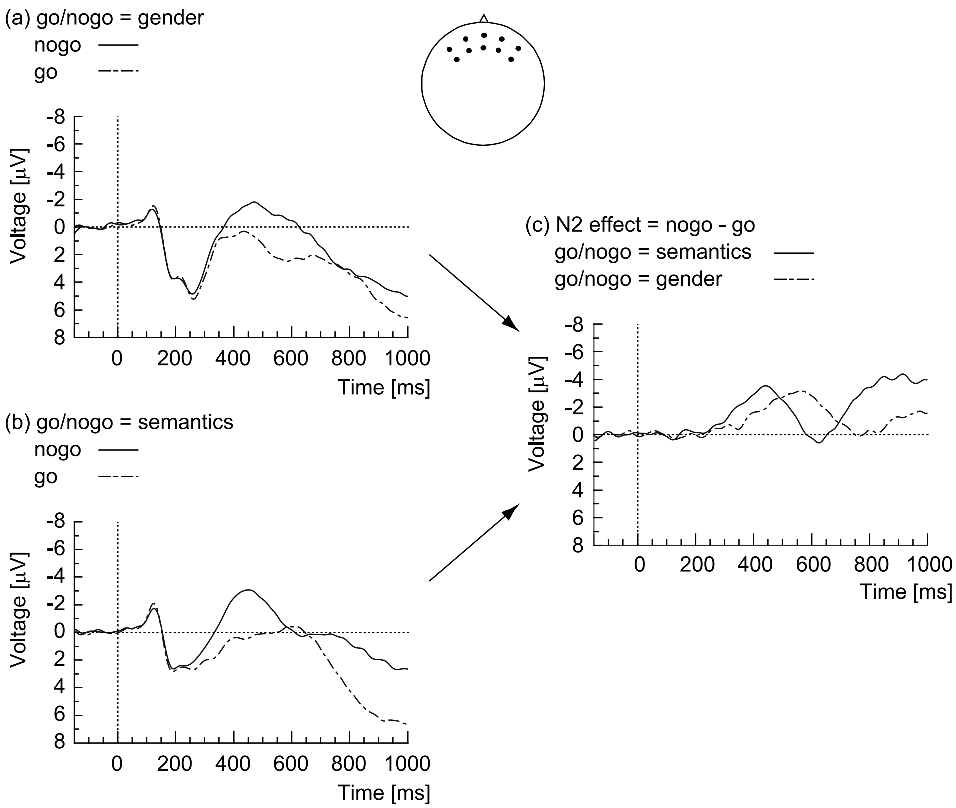

Figure 2-2. *Grand averages of the N2 inhibition-related effect, averaged across all 10 frontal electrodes indicated in the head schema. (a) Nogo- and go-trials in the go/nogo = gender task. (b) Nogo- and go-trials in the go/nogo = semantics task. (c) N2 net inhibition effect for both tasks, resulting from the subtraction of the nogo- and go-waveforms from (a) and (b).*

occurred around 400 ms. While onset of the main go-LRP seemed to occur somewhat later in the hand = semantics task (440 ms) than in the hand = gender task (400 ms), this difference was statistically not significant. The peak latency for the inhibition-related N2 effect in the go/nogo = semantics task was 100 ms earlier than in the go/nogo = gender task.

The significant LRP activity in the nogo-condition of the hand = semantics task (go/nogo = gender) indicates that semantic information was available before gender information. In this task, when semantic information becomes available, response preparation for the correct hand can begin. This in turn would surface as LRP activity. The LRP activity starting at 480 ms implies, thus, that semantic information was available at that time. We can also infer that response inhibition, based on gender information, has not set in yet – otherwise we should see no LRP activity at all. In other words, semantic information seems to have had an earlier influence on response preparation than gender information. This could reflect the retrieval order of these two word properties in language comprehension. Alternatively, it could reflect some strategic ordering in the use of information. Smid et al. (1992) pointed out that participants might give priority to information that is relevant for motor preparation (in this task, semantics), in order to gain fast responses. Information concerning execution/inhibition (here, gender) would be processed afterwards, since successful inhibition can be instantiated also at a later time. If such a strategic account were true, the particular word properties determining response hand and inhibition should be irrelevant for the occurrence of a nogo-LRP. Hence, we should find it also for the hand = gender (go/nogo = semantics) task. While we found early LRP activity in this task for both the go- and nogo-condition (treated in the next paragraph), no significant activity in the nogo-LRP occurred in parallel to the main go-LRP. As argued above, occurrence of LRP activity implies that the information determining response hand was available, which in this task is grammatical gender. The main go-LRP started around 400 ms and increased continuously until triggering an overt response. This suggests that gender was available in a reliable manner during this period. It seems reasonable to assume that this was also the case in the nogo-condition. However, we found no significant LRP activity for the nogo-condition around 400 ms or later. The absence of a nogo-LRP in this period suggests that response inhibition, based on semantic category information, was already in effect. This is in contradiction to the strategic account mentioned above, postulating that response preparation should occur before inhibition. It is rather in line with a language-related interpretation, which assumes that semantics is retrieved before gender.

A critical point regarding the interpretation of the LRP data is the early activation found for the go- and nogo-condition of the hand = gender task. Well before the onset of the main negativity, some correct movement preparation seems to have occurred (go-LRP: 260 to 310 ms; nogo-LRP: 140 to 260 ms). We would suggest that this is an artifact caused by the presence of diminutives in the materials, which always possess neuter gender and are orthographically marked by a suffix (e.g. *kerk-je*). For diminutives, the suffix would obviously allow a gender decision on an orthographic basis – which is why they were excluded from analysis. However, there might even be consequences for the common gender words, which did enter analysis. In every experimental block, there were about one quarter diminutives, one quarter intrinsically neuter gender nouns, and one half common gender nouns. Accordingly, from all words not carrying the diminutive suffix, two thirds were of common gender. Participants might have used this regularity for a guess, categorizing words without the diminutive suffix as probably having common gender. For common gender words, this would have actually resulted in a correct guess (although not for unmarked neuter words).

The guessed gender status then could have led to some correct preliminary motor preparation like we see in the presented data. Since there were also neuter gender words without the diminutive suffix, this strategy was not fail-safe and for accurate performance it was necessary to access lexically stored gender information. Therefore, participants probably stopped preparatory activity before it could trigger overt behavior. Note that the main go-LRP of the hand = gender task, which eventually triggered the overt responses, is temporally separated from the early activity in go- and nogo-waveform. If grammatical gender had been reliably retrieved at the time of the early LRP activations, one would expect that preparatory activity on go-trials would continuously increase from that moment on and develop into a full-blown LRP. The latter did not happen and in our view this suggests that early and late LRP activity in the hand = gender task reflect different processes. As outlined above, we would propose that activity in the early time window relates to guessing grammatical gender based on orthographic features, while activity in the late window relates to retrieving gender from the lexicon. We think that the suffix-checking strategy offers a viable explanation for the early LRP activity in the hand = gender task. Regarding the different timing of early activity in the go- and nogo-LRP, however, we must admit that we have no satisfying answer to offer and must leave the issue unresolved.

Taken together, the results from the nogo-LRPs and the N2 effect provide evidence that semantic category is available earlier than grammatical gender for written words presented in isolation.

A general issue regarding the interpretation of our study might be the use of two explicit categorization tasks to measure the retrieval of grammatical gender and semantic category. Forster (1979) proposed that categorization tasks have no direct access to language processing, but depend on extra read-out and decision processes, which co-determine the outcome for the dependent measures. This raises the question whether our findings actually reflect differences in the retrieval time for gender and semantic category or differences in those secondary task processes. In particular, if the semantic decisions in our experiment have a more direct access to semantic category representations than the gender decisions to grammatical gender representations, this would distort our view on the targeted retrieval time course. We cannot completely rule out such a possibility. One should consider, though, that we used ERP measures which reflect task-related processes at an earlier time than conventional behavioral measures. Although our ERP measures are not immune to strategic influences, they might avoid some effects emerging at later response stages. Schiller, Münte, Horemans, and Jansma (2003) investigated phonological regularities in German gender classes and their influence on gender decisions. While they found a significant effect for RTs in a simple go/nogo task, the peak latency of the inhibition-related N2 effect showed no reliable difference. It is undisputable that gender and semantic decisions contain some artificiality, but we would assume that participants have to rely on the representations underlying normal language processing to successfully carry out these tasks. There is now a considerable number of studies that have used the two-choice go/nogo paradigm to investigate time course issues in language processing (Abdel Rahman & Sommer, 2003; Abdel Rahman, Van Turennout, & Levelt, 2003; Rodriguez-Fornells, Schmitt, Kutas, & Münte, 2002; Schmitt et al., 2000; Schmitt, Rodriguez-Fornells et al., 2001; Schmitt, Schiltz, Zaake, Kutas, & Münte, 2001; Van Turennout et al. 1997; Van Turennout, Hagoort, & Brown, 1998). To summarize, drawing valid conclusions regarding the time course of gender and semantic retrieval from our results presupposes that gender decision and semantic decision have equivalent access to representations of grammatical gender and semantic category, respectively.

At the least, our experiment might be viewed as a control for potential modality effects in the study of Schmitt, Rodriguez-Fornells et al. (2001), who compared the timing of semantics and grammatical gender with the same experimental technique in the auditory modality. For the N2 effect, they determined an onset difference of 95 ms in favor of semantics and a peak latency difference of 69 ms in favor of semantics. The possibility had existed that cues to semantic and syntactic information were located in temporally separate stretches of the speech signal, thereby biasing the retrieval order (cf. Hagoort, 2003; Van den Brink & Hagoort, 2004). In that case, written words could have shown a different retrieval order, as all perceptual information becomes available at once with visual presentation. However, the timing of access to semantics and grammatical gender showed a similar profile for our written and their spoken stimuli.

Assuming the data of Schmitt, Rodriguez-Fornells et al. (2001) and of the current study reflect the time course of gender and semantic category retrieval, they challenge the hypothesis that processing order in language comprehension is simply reversed in relation to that in speech production. Theoretical motivation for the reversal hypothesis comes from Levelt et al.'s claim (1999), that speech production and language comprehension share the semantic and grammatical representations for words. Furthermore, Levelt et al. and other speech production theories (cf. Levelt, 1999) assume that semantic processing precedes syntactic processing. Empirical evidence for this comes from Schmitt, Rodriguez-Fornells et al.'s (2001) tacit picture-naming experiment, where the N2 effect had an earlier onset and peak latency for semantics than for grammatical gender. According to the reversal hypothesis, language comprehension should proceed from syntactic to semantic processing. However, this is not what Schmitt, Rodriguez-Fornells et al. and we found.

To investigate this apparent contradiction, Roelofs (personal communication) implemented a simulation in his WEAVER model based on our experiment. In this model, the presentation of a word provides the corresponding lemma node with input activation, which is then spreading to the appropriate gender node via a unidirectional connection (figure 2-3; for general features of the model and the relation of speech production and language

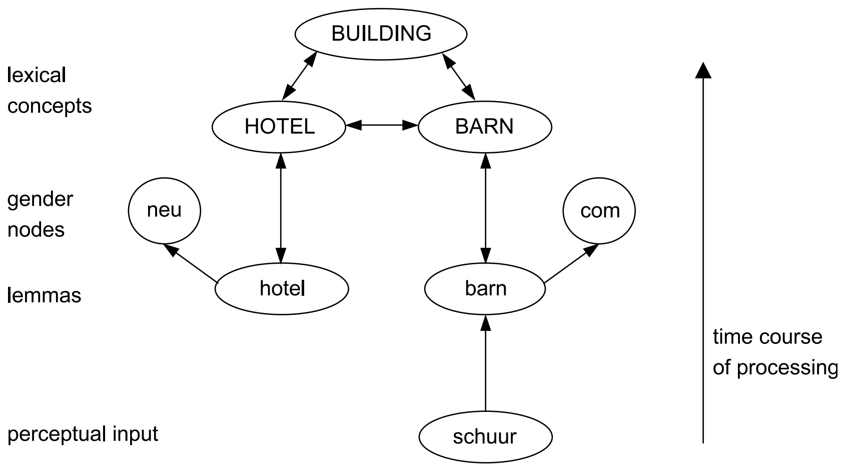

Figure 2-3. *Sketch of the WEAVER model as adapted for language comprehension. Connections with one arrowhead are unidirectional and connections with two arrowheads are bidirectional (all excitatory). Activation starts to spread from the perceptual input to the corresponding lemma. From there, gender nodes (neu = neuter gender, com = common gender) and a corresponding concept node receive activation. The concept node can send activation back to its lemma and to superordinate concepts (building) and category coordinates (hotel).*

comprehension, cf. Roelofs, 1992; Roelofs, Meyer, & Levelt, 1996). From the lemma, activation also spreads to the respective concept node, then to the corresponding semantic category node, but also to other category exemplars, which again feed activation to the semantic category. The connections from lemmas to concepts and among concepts are bidirectional. Although in the simulation, the gender nodes received the first portions of activation earlier than semantic category nodes, semantic category nodes reached the activation threshold set for final selection earlier than the gender nodes. According to Roelofs, this arises from the dynamic aspects of the model. While gender nodes receive input from a lemma via one unidirectional connection, semantic category nodes are embedded in an extensive network with several inputs and bidirectional connections. The latter allows the reverberation of activation, which leads to an accelerated accumulation of activation for the semantic category nodes. The outcome of the simulation means that the hypothesis of shared semantic and syntactic representations for speech production and language comprehension is still a possibility and that we cannot refute it on the grounds of our time course results.

Our data show that there is a measurable time difference in the availability of semantic category and grammatical gender information. This excludes a serial discrete architecture where first retrieval of syntactic information has to finish before retrieval of semantic information can begin. The results leave room for a serial discrete system with retrieval of semantics before syntax as well as for a parallel system, with semantic retrieval being faster than syntactic retrieval (cf. Abdel Rahman & Sommer, 2003). Roelofs' simulation indicates that in a parallel architecture the onset of access to semantic and syntactic representations might even have the opposite timing profile as final retrieval.

Research on the details of accessing semantic and syntactic word properties in language comprehension has been sparse in the past. Although the fields of word recognition and sentence processing make reference to semantic and syntactic word properties, they often leave the specifics of their retrieval open. We believe our finding that semantic category information is available earlier than grammatical gender information when participants read single words contributes to a more complete picture of language comprehension. It puts restrictions on theories and models of language comprehension, especially on those that deal with the use of stored semantic and syntactic information.

In the sentence processing literature, there is a long-lasting debate about when different kinds of lexical information contribute to the construction of a syntactic structure. Serial discrete models assume that this parsing process relies purely on syntactic lexical information at an early stage and takes semantic information into account only later (Forster, 1979; Frazier, 1989; Friederici, 2002). In contrast, constraint-based models assume that semantic and discourse information can exert an immediate influence (MacDonald et al., 1994; Trueswell & Tanenhaus, 1994). Since we presented isolated words in our experiment, we cannot directly derive statements on sentence processing. In fact, from the point of view of serial discrete models, it might seem irrelevant when semantic and syntactic word properties become available. Time course assumptions in such models rather describe when certain word properties get used in parsing and not when they are, in principle, available. However, for all we know about the incremental nature of language processing, the assumption that semantic information that is available earlier than syntactic lemma information, will be used later in on-line sentence processing, seems highly implausible. In contrast to serial discrete models, the constraint-based approach emphasizes that lexical processing, that is, the access to semantic and syntactic word properties, and the building of a sentence structure are intimately linked. All available lexical information of a word determines how the existing sentence and discourse structures changes through the integration of the word, while the sentence and discourse structures can also have an impact on the activation of lexical information. Representatives of the constraint-based approach have made no commitments to the time course of access for different word properties, focusing on the interactive character of lexical and sentence processing. Nonetheless, the finding that during the presentation of isolated words certain aspects of lexical semantic information are available earlier than certain aspects of syntactic information, might mean that lexical semantic information influences sentence structure building earlier than lexical syntactic information. Just as much, a biasing sentence or discourse context might alter the time course in which lexical semantic and syntactic information become available.

To know when certain word properties are available may also put constraints on certain word recognition models that assume interactions among orthographic, phonological, semantic, and syntactic representations of a word (Van Orden, Pennington, & Stone, 1990; Plaut, McClelland, Seidenberg, & Patterson, 1996). Such models would have to accommodate findings on the time course of availability of semantic and syntactic word properties and be able to mirror these findings in simulations. This obviously concerns the dynamics of the semantic and syntactic representations, but because of the extensive interactivity in these models, there may also be consequences for the dynamics of orthographical and phonological representations. Plaut et al. (1996, simulation 4), for example, have shown that an orthography-to-phonology mapping in a PDP network is learned in different ways, depending on the presence or absence of an orthography-to-semantics-to-phonology pathway. In analogy to that, different patterns of access to semantic and syntactic representations of a word could have distinctive effects on the processing in the orthographical and phonological parts of the word recognition system.

Our study probed the processes of semantic and syntactic access in language comprehension, which lie at the junction of word recognition and sentence processing. Using electrophysiological recordings to monitor these covert processes with high temporal resolution, we could establish that semantic information is available earlier than syntactic information. How the differential temporal availability of semantic and syntactic word properties fits into the dynamics of word identification and sentence processing remains a topic for future research.

References

Abdel Rahman, R., & Sommer, W. (2003). Does phonological encoding in speech production always follow the retrieval of semantic knowledge? Electrophysiological evidence for parallel processing. *Cognitive Brain Research, 16,* 372-382.

Abdel Rahman, R., Van Turennout, M., & Levelt, W.J.M. (2003). Phonological encoding is not contingent on semantic feature retrieval: An electrophysiological study on object naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*, 850-860.

Allopenna, P.D., Magnuson, J.S., & Tanenhaus, M.K. (1998). Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models. *Journal of Memory and Language, 38*, 419-439.

American Electroencephalographic Society (1991). Guidelines for standard electrode position nomenclature. *Journal of Clinical Neurophysiology, 8,* 200-202.

Balota, D.A. (1994). Visual word recognition: The journey from features to meaning. In M.A. Gernsbacher (Ed.), *Handbook of psycholinguistics* (pp. 303-358). San Diego: Academic Press.

Caramazza, A. (1997). How many levels of processing are there in lexical access? *Cognitive Neuropsychology, 14,* 177-208.

CELEX Dutch database (Release N31) [On-line]. (1990). Retrieved April 18, 2005, from http://www.mpi.nl/world/celex

Coles, M.G.H., Gratton, G., & Donchin, E. (1988). Detecting early communication: Using measures of movement-related potentials to illuminate human information processing. *Biological Psychology, 26,* 69-89.

Corbett, G.G. (1991). *Gender*. Cambridge: Cambridge University Press.

De Jong, R., Wierda, M., Mulder, G., & Mulder, L.J.M. (1988). Use of partial stimulus information in response processing. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 682-692.

Donaldson, B.C. (1987). *Dutch reference grammar* (3rd ed.). Leiden: Nijhoff.

Eimer, M. (1993). Effects of attention and stimulus probability on ERPs in a go/nogo task. *Biological Psychology, 35,* 123-138.

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (1999). ERP components in go/nogo tasks and their relation to inhibition. *Acta Psychologica, 101,* 267-291.

Forster, K.I. (1979). Levels of processing and the structure of the language processor. In W.E. Cooper & E.C.T. Walker (Eds.), *Sentence processing: Psycholinguistic studies presented to Merrill Garrett* (pp.27-85). Hillsdale, NJ: Erlbaum.

Frazier, L. (1989). Against lexical generation of syntax. In W.D. Marslen-Wilson (Ed.), *Lexical representation and process* (pp. 505-528). Cambridge, MA: MIT Press.

Friederici, A.D. (2002). Towards a neural basis of auditory sentence processing. *Trends in Cognitive Sciences, 6,* 78-84.

Friederici, A.D., & Jacobsen, T. (1999). Processing grammatical gender during language comprehension. *Journal of Psycholinguistic Research, 28*, 467-484.

Friederici, A.D., Pfeifer, E., & Hahne, A. (1993). Event-related brain potentials during natural speech processing: Effects of semantic, morphological, and syntactic processing. *Cognitive Brain Research, 1*, 183-192.

Gemba, H., & Sasaki, K. (1989). Potential related to no-go reaction of go/no-go hand movement task with color discrimination in human. *Neuroscience Letters, 101,* 263-268.

Hagoort, P. (2003). How the brain solves the binding problem for language: A neurocomputational model of syntactic processing. *Neuroimage, 20,* S18-S29.

Hahne, A., & Jescheniak, J.D. (2001). What's left if the Jabberwock gets the semantics? An ERP investigation into semantic and syntactic processes during auditory sentence comprehension. *Cognitive Brain Research, 11*, 199-212.

Jodo, E., & Kayama, Y. (1992). Relation of a negative ERP component to response inhibition in a go/nogo task. *Electroencephalography and Clinical Neurophysiology, 82,* 477-482.

Kok, A. (1986). Effects of degradation of visual stimuli on components of the event-related potential (ERP) in go/nogo reaction tasks. *Biological Psychology, 23,* 21-38.

Kornhuber, H.H., & Deecke, L. (1965). Hirnpotentialänderungen bei Willkürbewegungen und passiven Bewegungen des Menschen: Bereitschaftspotential und reafferente Potentiale [Brain potential changes associated with voluntary and passive movements in humans: Readiness potential and reafferent potentials]. *Pflügers Archive, 284,* 1-17.

Kutas, M., & Donchin, E. (1980). Preparation to respond as manifested by movement-related brain potentials. *Brain Research, 202,* 95-115.

Kutas, M., & Van Petten, C.K. (1994). Psycholinguistics electrified. In M.A. Gernsbacher (Ed.), *Handbook of psycholinguistics* (pp. 83-143). San Diego: Academic Press.

Levelt, W.J.M. (1999). Models of word production. *Trends in Cognitive Sciences, 3*, 223-232.

Levelt, W.J.M., Roelofs, A., & Meyer, A.S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences, 22,* 1-75.

Lippold, O.C.J. (1967). Electromyography. In P.H. Venables & I. Martin (Eds.), *A manual of psychophysiological methods* (pp. 245-297). Amsterdam: North-Holland Publishing Company.

MacDonald, M.C., Pearlmutter, N.J., & Seidenberg, M.S. (1994). Lexical nature of syntactic ambiguity resolution. *Psychological Review, 101,* 676-703.

Marslen-Wilson, W.D. (1987). Functional parallelism in spoken word recognition. *Cognition, 25*, 71-102.

McClelland, J.L., & Elman, J.L. (1986). The TRACE model of speech perception. *Cognitive Psychology, 18*, 1-86.

Miller, J., & Hackley, S.A. (1992). Electrophysiological evidence for temporal overlap among contingent mental processes. *Journal of Experimental Psychology: General, 121,* 195-209.

Norris, D. (1994). Shortlist: A connectionist model of continuous speech recognition. *Cognition, 52*, 189-234.

Osman, A., Bashore, T.R., Coles, M.G.H., Donchin, E., & Meyer, D.E. (1992). On the transmission of partial information: Inferences from movement-related brain potentials. *Journal of Experimental Psychology: Human Perception and Perception, 18,* 217-232.

Pfefferbaum, A., Ford, J.M., Weller, B.J., & Kopell B.S. (1985). ERPs to response production and inhibition. *Electroencephalography and Clinical Neurophysiology, 60,* 423-434.

Plaut, D.C., McClelland, J.L., Seidenberg, M.S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103,* 56-115.

Radeau, M., Morais, J., Mousty, P., Saerens, M., & Bertelson, P. (1992). A listener's investigation of printed word processing. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 861-871.

Rastle, K., & Coltheart, M. (1999). Serial and strategic effects in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 482-503.

Rodriguez-Fornells, A., Schmitt, B.M., Kutas, M., & Münte, T.F. (2002). Electrophysiological estimates of the time course of semantic and phonological encoding during listening and naming. *Neuropsychologia, 40,* 778-787.

Roelofs, A. (1992). A spreading-activation theory of lemma retrieval in speaking. *Cognition, 42,* 107-142.

Roelofs, A., Meyer, A.S., & Levelt, W.J.M. (1996). Interaction between semantic and orthographic factors in conceptually driven naming: Comment on Starreveld and La Heij (1995). *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 246-251.

Schiller, N.O., Münte, T.F., Horemans, I., & Jansma, B.M. (2003). The influence of semantic and phonological factors on syntactic decisions: An event-related brain potential study. *Psychophysiology, 40*, 869-877.

Schmitt, B.M., Münte, T.F., & Kutas, M. (2000). Electrophysiological estimates of the time course of semantic and phonological encoding during implicit picture naming. *Psychophysiology, 37,* 473-484.

Schmitt, B.M, Rodriguez-Fornells, A., Kutas, M., & Münte, T.F. (2001). Electrophysiological estimates of semantic and syntactic information access during tacit picture naming and listening to words. *Neuroscience Research, 41,* 293-298.

Schmitt, B.M., Schiltz, K., Zaake, W., Kutas, M., & Münte, T.F. (2001). An electrophysiological analysis of the time course of conceptual and syntactic encoding during tacit picture naming. *Journal of Cognitive Neuroscience, 13*, 510-522.

Schriefers, H., & Teruel, E (2000). Grammatical gender in noun phrase production: The gender interference effect in German. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*, 1368-1377.

Simson, R., Vaughan, H.G., & Ritter, W. (1977). The scalp topography of potentials in auditory and visual go/nogo tasks. *Electroencephalography and Clinical Neurophysiology, 43,* 864-875.

Smid, H.G.O.M., Mulder, G., Mulder, L.J.M., & Brands, G.J. (1992). A psychophysiological study of the use of partial information in stimulus-response translation. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 1101-1119.

Theta/phi-coordinates of equidistant montage no. 10. (n.d.). Retrieved February 3, 2005, from http://www.easycap.de/easycap/e/downloads/M10_ThetaPhi.htm

Thorpe, S., Fize, D., & Marlot, C. (1996). Speed of processing in the human visual system. *Nature, 381,* 520-522.

Trueswell, J.C., & Tanenhaus, M.K. (1994). Toward a constraint-based lexicalist approach to syntactic ambiguity resolution. In C. Clifton, L. Frazier, & K. Rayner (Eds.), *Perspectives on sentence processing* (pp. 155-179). Hillsdale, NJ: Erlbaum.

Ulrich, R., & Miller, J. (2001). Using the jackknife-based scoring method for measuring LRP onset effects in factorial designs. *Psychophysiology, 38*, 816-827.

Van Berkum, J.J.A. (1996). *The psycholinguistics of grammatical gender: Studies in language comprehension and production*. Nijmegen: Nijmegen University Press.

Van den Brink, D., & Hagoort, P. (2004). The influence of semantic and syntactic context constraints on lexical selection and integration in spoken-word comprehension as revealed by ERPs. *Journal of Cognitive Neuroscience, 16*, 1068-1084.

Van Orden, G.C., Pennington, B.F., & Stone, G.O. (1990). Word identification in reading and the promise of subsymbolic psycholinguistics. *Psychological Review, 97,* 488-522.

Van Turennout, M., Hagoort, P., & Brown, C.M. (1997). Electrophysiological evidence on the time course of semantic and phonological processes in speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 787-806.

Van Turennout, M., Hagoort, P., & Brown, C.M. (1998). Brain activity during speaking: From syntax to phonology in 40 milliseconds. *Science, 280,* 572-574.

Zorzi, M. (2000). Serial processing in reading aloud: No challenge for a parallel model. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 847-856.

PRIMING ACCESS OF GRAMMATICAL GENDER IN LANGUAGE COMPREHENSION

Chapter 3

Oliver Müller and Peter Hagoort (submitted)

Abstract

A diverse range of languages categorizes their nouns according to grammatical gender. This study investigated the access to grammatical gender in language comprehension, in particular, whether gender access for a noun can be primed by another noun. Participants saw prime-target noun pairs displayed on a computer screen, under different SOA conditions. They had to decide on the gender of the target, with the prime being gender congruent or gender incongruent. For SOAs of 100 ms and 0 ms, gender congruent prime-target pairs showed faster responses than incongruent ones, whereas there was no effect of gender congruity for an SOA of 300 ms. We discuss some possible mechanisms which can account for the gender congruity effect. Furthermore, we demonstrate that a localist computational model with competition between gender representations (WEAVER, by Roelofs, 1992) is able to capture our empirical findings.

Introduction

The process of word recognition makes available semantic and syntactic word properties. On the basis of these word properties, sentence processing can create larger semantic and syntactic structures, eventually leading to the (re)construction of a meaningful message from an input string of words. The semantic properties of a word serve as building blocks for the overall meaning of a text or discourse, but can also influence the formation of syntactic structures in language comprehension (e.g., McRae, Ferretti, & Amyote, 1997; Taraban & McClelland, 1988). Syntactic word properties provide information on how words relate to each other, contributing to the formation of syntactic structures and frequently governing morphological processes. We want to focus here on one particular syntactic property, namely the grammatical gender of nouns. Many languages of varying descent categorize their nouns into grammatical genders, including the Indo-European French, the Semitic Hebrew, and the Bantu language Swahili (cf. Corbett, 1991). Although labels for grammatical gender often derive from biological gender, nouns without such a semantic source of classification nonetheless have a certain grammatical gender. In French, for example, which differentiates a masculine and a feminine grammatical gender, the word for house carries feminine gender. The gender assignment for nouns without biological gender varies among languages: The word for house has masculine gender in Russian and neuter gender in German. The lacking systematicity makes it plausible that grammatical gender (for nouns without biological gender) is a syntactic property, represented separately in the mental lexicon (see also Hagoort & Brown, 1999).

A crucial characteristic of grammatical gender, placing it in the syntactic domain, is the mechanism of gender agreement: Depending on the language at hand, grammatical gender controls the form of certain words associated with a noun, such as articles, adjectives, pronouns, and so forth – they have to agree with the gender of the noun. In Dutch, which distinguishes between a common gender and a neuter gender, gender agreement determines the form of the singular definite article (for other targets of gender agreement in Dutch see Deutsch & Wijnen, 1985). The article takes the form *de* for common gender nouns and *het* for neuter gender nouns. Translating ***The** farmer caught **the** lamb* into Dutch results in ***De** boer pakte **het** lam*, since *boer* has common gender and *lam* has neuter gender.

Investigators have made several proposals regarding the functionality of grammatical gender in language comprehension. Bates and MacWhinney (1989) suggested that gender agreement between a noun and subsequently occurring words (e.g., pronouns) could help in keeping track of referents in a complex discourse. Desrochers (1986) argued that gender agreement would in general increase the coherence of a sentence. Others proposed that grammatical gender facilitates word recognition, with a (correctly) gender marked article or adjective priming the recognition of the subsequent noun (Bates, Devescovi, Hernandez, & Pizzamiglio, 1996; Grosjean, Dommergues, Cornu, Guillelmon, & Besson, 1994). However, none of these hypotheses has received unequivocal empirical support and it remains an open issue whether grammatical gender has some functionality in language processing at all.

Although we cannot say anything definite about the functionality of grammatical gender, several studies measuring event-related brain potentials have found evidence that gender agreement is engaging syntactic processes during language comprehension. Hagoort and Brown (1999) had participants read Dutch sentences, with the definite article and the noun agreeing or disagreeing in grammatical gender. The condition with a gender violation on the noun displayed a P600/SPS, which in the domain of language processing is taken to index syntactic processing (cf. Hagoort, Brown, & Osterhout, 1999; Osterhout, McLaughlin, & Bersick, 1997). Gunter, Friederici, and Schriefers (2000) investigated gender violations between article and noun in German, and Deutsch and Bentin (2001) employed gender violations between subject and predicate in Hebrew. In both studies, gender violation resulted in left anterior negativities, which are also associated with syntactic processing (cf. Friederici, 1995, 2002). A P600/SPS occurred only in some conditions of their respective designs, which included additional semantic and morphological manipulations. The fact that gender agreement affects ERP components related to syntactic processing does not only identify the kind of higher level processes it is involved in. It also argues for grammatical gender being a syntactic word property rather than being semantically specified.

One can think of several ways for representing grammatical gender in the language comprehension system. Spinelli and Alario (2002) discuss whether grammatical gender is bound to phonological or semantic word representations. In two experiments they used French homophones, the two different meanings of which were associated with a different grammatical gender (e.g., *le sel* = the salt, *la selle* = the saddle). When homophone stimuli were auditorily presented as single words, semantic priming occurred for associates of both word meanings in a lexical decision task. However, when a homophone was presented together with a gender marking definite article, only associates of the meaning being in line with the gender information received priming. Spinelli and Alario speculate that if homophones have a single phonological representation, the observed gender effect must have taken place at the semantic level and the two different meaning representations might be "tagged with a grammatical gender node" (p. 465). They deem gender marking at the semantic level improbable, though, since grammatical gender classification is not strongly influenced by semantic factors in French. Furthermore, they argue that gender tagging at the semantic level would have undesirable consequences for speakers of two languages where corresponding words differ in gender: Such words would need to have two separate meaning representations, each tagged for the respective gender, to allow the bilingual listener to discern the words by their gender. Therefore, they assume that homophones have two separate phonological entries, tagged with the specific gender, and that the observed gender effect originates at this level.

Friederici and Jacobsen (1999) mention another possibility for representing gender in language comprehension, which is borrowed from models of speech production (Dell, 1986; Harley, 1993; Kempen & Hoenkamp, 1987; Levelt, 1989; Levelt, Roelofs, & Meyer, 1999; Stemberger, 1985). It involves a distinct level of syntactic representation, in between a form-based and a semantic level. Each word is represented as a lemma node with associated syntactic features such as gender. Levelt et al. (1999) actually assume for their WEAVER model that the semantic and lemma level are shared by speech production and language comprehension. Branigan, Pickering, and Cleland (2000; Cleland & Pickering, 2003) also argue for a shared lemma level, based on the observation that hearing sentences with certain syntactic structures primes the use of those structures in language production. Following the architecture of WEAVER, gender access in language comprehension would entail that the perception of a written or spoken word activates a lemma which in turn sends activation to a grammatical gender node via a unidirectional link (Roelofs, 1992, 2003; Roelofs, Meyer, & Levelt, 1996). There is one node per gender class to which all noun lemmas of a particular gender project.

Bates et al. (1996) suggest a fundamentally different language system in their discussion of gender priming effects, following Elman's (1990, 1993) work on distributed language representations in simple recurrent networks. This view disposes of localist notions of representation, that is, of a word or a gender class corresponding to one particular node in a network. Bates et al. envisage words as being represented in a multidimensional vector space, with the instantiation of a word corresponding to some position in that space. Elman (1990) has shown that within such a network words with similar grammatical properties (e.g. nouns and verbs) form clusters in vector space. One could also conceive of a clustering of words with a particular gender, such that words of the same gender are closer to each other than to words of different gender.

Research on language comprehension has repeatedly employed grammatical gender to investigate syntactic context effects on word recognition. In a typical experiment, a gender-marked prime (e.g. an article or adjective) precedes a noun with congruent or incongruent gender. Faster response times for gender congruent than gender incongruent trials have been found in a variety of tasks like lexical decision, naming, word repetition, and gender decision (for a review see Friederici & Jacobsen, 1999). Note that the article-noun and adjective-noun pairs commonly used in these experiments form naturally occurring phrases. As such, a gender incongruent pair violates gender agreement and parsing mechanisms might detect this ungrammaticality, leading to a processing delay. Accordingly, Friederici and Jacobsen propose that a congruity check could be the source of the gender congruity effect. Grosjean et al. (1994) concede that gender congruity effects could partly have a syntactic origin, but maintain that there might also be a lexical contribution, with advance gender information activating nouns of the respective gender. They suggest that the usage of gender congruent and incongruent noun-noun pairs would avoid the grammaticality confound since they do not underlie gender agreement. A gender congruity effect found with noun-noun pairs could then be taken as a strictly lexical effect. Within a localist framework for gender representation analogous to Levelt et al.'s (1999) model, this would mean that the prime noun activates its associated gender node and from the gender node activation would spread further to all nouns which share that gender. As Friederici and Jacobsen have pointed out, that last step would require a bidirectional connection between noun and gender node, whereas Levelt et al. assume a unidirectional connection in their original proposal. Furthermore, gender classes usually contain a large number of nouns and therefore activation from the gender node would spread to many words, not only enhancing the activation of the target but also of other nouns (cf. Tanenhaus, Dell, & Carlson, 1987). Consequently, the discriminatory benefit for word recognition might be very small and actually not observable.

However, given a gender representation as suggested in Levelt et al. (1999), gender congruity in noun-noun pairs should at least have a clear effect on gender access. Three features make such an effect plausible. First, nouns of the same gender share the same gender node. Second, the gender nodes gradually receive activation. Third, the selection of a gender node depends on its activation level (we will present a detailed implementation in the discussion). If Spinelli and Alario (2002) adapted these features, priming of gender access by nouns would also occur within their model. In a system with the specified features, a prime would activate a certain gender node and gender access for a noun with identical gender should be faster: Activation from prime and target combine, so that activation-based selection occurs faster. The selection of a gender node might additionally be controlled by a checking mechanism, which assures that the gender node belongs to the current target (as assumed for WEAVER, cf. Levelt et al., 1999; Roelofs, 1992, 2003; Roelofs, Meyer, & Levelt, 1998). Such a checking mechanism would prevent gender selection to happen purely on the ground of words preceding the noun. This seems important, since a situation can occur where a gender-marked word, such as an adjective, immediately precedes a noun, although it relates to another noun, as pointed out by Bates et al. (1996, pp. 1000-1001). The effect of a prime indicating a different gender as the target noun depends on some additional premises. If gender selection is based only on a node passing some absolute activation threshold (plus a checking mechanism), a gender mismatch would not harm gender access of the noun. Gender access would still be slower than with a gender match, though, because of the relative lack of supporting activation. In case there is competition among gender nodes, mismatching gender information would slow down gender access for the target noun.

As an alternative, one could conceive of a localist network, where the selection of gender nodes does not depend on activation levels. Instead, the recognition of a word would automatically give access to the associated gender. After all, grammatical gender is a fixed property of a noun and there is no theoretical need to assume a separate selection process or even competition among gender nodes. In such a system, the gender congruity of primes would have no influence on gender access.

Regarding the vector space representation suggested by Bates et al. (1996), priming of gender access seems plausible. The processing of word sequences corresponds to movements in the vector space (cf. Elman, 1993). Preceding context determines a position in vector space, which can be near or far from the position which the next word will take. This indicates how well the context has prepared the system for the processing of the next word. Bates et al. describe this for adjective-noun pairs: a gender-marked adjective would take a position in vector space which is already near the nouns of the corresponding gender class. As the noun comes up, there is some distance to be traveled from the adjective position to the noun position. If the noun belongs to a different gender class as indicated by the adjective, this distance is bigger than if the noun belongs to the gender class as indicated by the adjective. Bates et al. propose that gender priming only takes place in connection with the processing of gender agreement. They are concerned that gender-marked words that accidentally precede a noun but are not syntactically linked to it might otherwise have a disrupting effect.[1] Nonetheless, the sketched vector space account of priming gender access should in principle be applicable to all primes carrying gender information, that is, also to noun primes.

In this study, we want to explore the possibility that access to the grammatical gender of a noun is influenced by a noun prime. As explicated above, some models of gender representation predict that gender access should be faster for gender congruent than incongruent primes. In contrast, a model where the selection of a noun automatically makes available the associated gender predicts that there should be no influence of gender congruity. We visually presented Dutch nouns in prime-target pairs, with words having identical or different gender. Gender access was measured with a gender decision task (cf. Radeau & Van Berkum, 1996): Participants had to decide whether the target had common or neuter gender by pressing a respective push-button, while ignoring the prime. We also varied the time with which the prime preceded the target, using SOAs of 0 ms, 100 ms, and 300 ms. The SOA manipulation was introduced in case the occurrence or strength of a gender congruity effect depended on the temporal relation of prime and target presentation.

1. Nicol, Forster, and Veres (1997) and Pearlmutter, Garnsey, and Bock (1999) examined subject-verb number agreement in reading and actually found a disruptive effect of a plural noun occurring between a singular noun and its verb. Although grammatical gender and number are different phenomena, this shows that an agreement process might be permeable to irrelevant information.

Method

Participants

24 native speakers of Dutch (6 male) participated in the experiment, with age being on average 24 years (range: 18 to 34 years). They were paid for taking part in the experiment.

Materials

For purposes of a follow-up experiment, experimental stimuli came from twelve different semantic categories. Words from eight categories had already been used in an earlier study employing gender decisions, showing consistent gender classification (Chapter 2 & Hagoort, submitted). To ensure that the words from the other four categories were also consistently classified, we conducted a paper-and-pencil pretest. Thirty participants received a randomized word list and had to indicate whether a word carried common or neuter gender. On the basis of these data, consistently categorized items were chosen for the four new categories. The item selection resulted in 192 critical words. For every category, one third of the words had neuter gender and the remaining words had common gender. The distributions of word length in letters and lemma frequency substantially overlapped for words of common and neuter gender.

Procedure

Participants were seated in a dimly lit sound-attenuating booth, facing a computer screen, placing their left and right index finger on a respective response button. The word stimuli were displayed in white Arial letters against a black background. Targets appeared in capital letters and primes in small letters.

There were three different SOA conditions (0 ms, 100 ms, 300 ms), with eight participants in each condition. A trial started with the presentation of an asterisk in the centre of the screen for 500 ms, after which the screen turned blank. In the SOA=0 condition, the screen was blank for 500 ms, then prime and target appeared at complementary positions above and below the centre of the screen. The blank period in the SOA=100 condition lasted 400 ms, after which the prime appeared at a position above or below the centre of the screen, followed 100 ms later by the target which appeared at the complementary position. The screen stayed blank for 300 ms in the SOA=300 condition, then the prime appeared in the centre of the screen for 300 ms and was replaced by the target. In all conditions, the target stayed on the screen for 1000 ms (together with the prime, in case of SOA = 0 and 100). Finally, the screen turned blank for 1000 ms, before a new trial began with an asterisk.

Participants performed a simple gender decision task on the target, indicating with a left or right button press whether it had common or neuter gender. The instruction told participants to ignore the prime.

A session consisted of four blocks, alternating in the assignment of grammatical gender to the response hand. The gender-hand assignment for the blocks was balanced across participants within a given SOA condition. The first 32 trials of a block served practice purposes, they comprised extra material and did not enter analysis. As indicated above, the experimental material contained twice as many common gender than neuter gender words. However, every block contained an equal number of common and neuter gender words. To this end, a particular block included half of the common gender words, but all neuter gender words. The complete set of common gender words appeared across the first two blocks and across the last two blocks. Each word chosen for a block served once as target and once as prime. Across blocks, neuter gender words occurred four times as target, common gender words occurred twice as target. However, only the first two presentations of neuter gender words entered analysis.

Prime-target pairs were chosen pseudorandomly for every participant, with the restriction that primes and targets came always from different semantic categories. For every block, six category pairings were selected, covering all semantic categories. Targets from one category would then be combined with primes from the other category of the pairing, and vice versa. The use of the category pairings was balanced across blocks. We further made sure that prime-target pairs did not share the onset, did not rhyme, and had no semantic or associative relationship. Words within a block were allowed only once to occur together in a prime-target pair. Per block, half of the targets from a particular gender-category combination (e.g., common gender + animal) appeared with a gender congruent prime and the other half with a gender incongruent prime. Over the whole session, a particular target word occurred equally often with a congruent and an incongruent prime. In the SOA = 0 and SOA = 100 condition, targets from a given gender-category combination appeared with the same probability in the upper and the lower position, within a block. Finally, the trial order of prime-target pairs was pseudorandomized with the following restrictions: Prime-target pairs belonging to a given category pairing were presented consecutively, with a short break before prime-target pairs from another pairing were shown. The same target position and target gender occurred no more than three times in a row, and at least one trial intervened before a word from a prime-target pair was presented again. The whole session took approximately one hour. After half of the blocks, participants got a break of several minutes.

Results

Incorrect push-button responses and responses occurring later than 1500 ms after target presentation counted as errors and were excluded from the RT analysis. For one participant a few trials were missing due to technical failure and another participant reported that he had followed the reverse instruction on the start of a particular block – these trials were excluded from RT as well as accuracy analyses. ANOVAs on the RT and error percentage

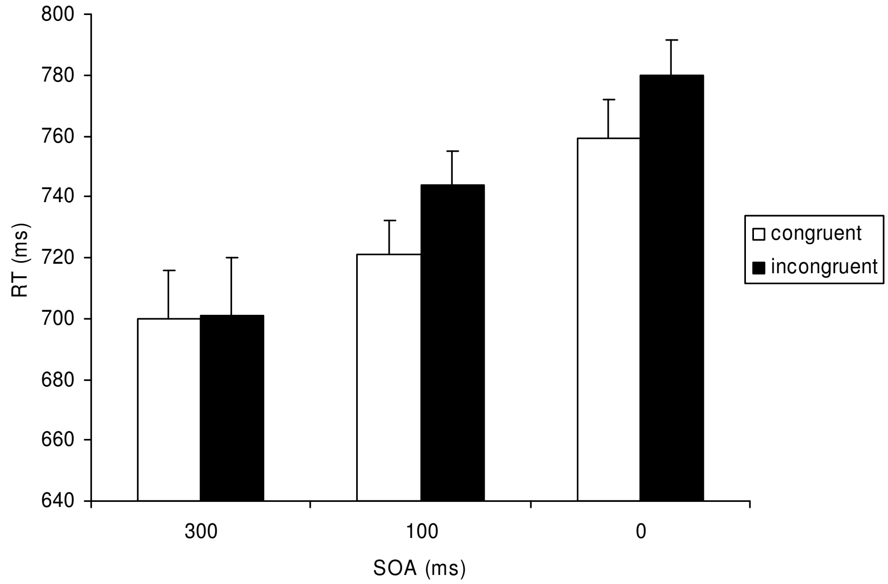

Figure 3-1. *Mean RTs across participants (with standard error bars) for the gender decision task at the three SOAs, split up for gender congruent and gender incongruent primes.*

averages across participants contained the between-participant factor SOA and the within-participant factors Gender Congruity and Target Gender.

RTs for gender congruent prime-target pairs were lower than for gender incongruent pairs in the SOA = 0 and SOA = 100 conditions, but virtually identical in the SOA = 300 condition (see figure 3-1). In the ANOVA the main effects of SOA ($F(2,21) = 6.8$, $MSE = 5554.3$, $p = .005$), gender congruity ($F(1,21) = 15.4$, $MSE = 353.5$, $p = .001$), and target gender ($F(1,21) = 14.4$, $MSE = 1269.9$, $p = .001$) reached significance. The latter reflected the fact that responses to common gender targets were faster than to neuter gender targets (720 ms vs. 748 ms). The interaction of SOA by gender congruity was the only significant one ($F(2,21) = 3.6$, $MSE = 353.5$, $p = .047$). We conducted pairwise comparisons among the three SOA levels, using the Bonferroni procedure to control the familywise α error rate, so that a p value of .0167 (= .05/3) for each single comparison was equivalent to an overall α rate of .05. We found that the RT for SOA = 0 was significantly higher than for SOA = 300 ($t(21) = 3.7$, $SE = 18.6$, $p = .001$): 769 ms versus 700 ms. Furthermore, we computed simple effects of gender congruity on all levels of SOA, to which the same Bonferroni corrected error rate applied. This resulted in a significant effect for SOA = 0 ($t(7) = 2.6$, $SE = 8.1$, $p = .035$) and SOA = 100 ($t(7) = 4.5$, $SE = 5.2$, $p = .003$), but not for SOA = 300 ($t(7) = .1$, $SE = 6.4$, $p = .923$).

The ANOVA on the accuracy data showed no significant effects involving gender congruity. There was only a significant main effect of target gender, with $F(1,21) = 25.3$, $MSE = 14.1$, and $p < .001$. Common gender targets elicited fewer errors than neuter gender targets (4.1% vs. 8.0%).

Discussion

This study investigated the access to the grammatical gender of nouns, specifically looking at the influence of noun primes with identical or different gender. We found an effect of gender congruity on RT, with responses to congruent prime-target pairs being faster than to incongruent pairs. Inspection of the simple effects for the three SOAs revealed that only the SOA = 0 and 100 conditions produced significant priming, while the SOA = 300 showed virtually no difference between congruent and incongruent pairs. The SOA = 300 condition figures the biggest temporal distance between prime and target appearance and this might have led to the lack of priming. One possibility is that the prime caused only a short-lived activation of its gender representation and that this activation had already decayed in the SOA = 300 condition when the gender of the target was accessed. The bigger temporal distance might also have made it easier to discriminate between prime and target. This in turn would make it possible to ignore or suppress activation from the prime, thereby shutting out irrelevant and potentially harmful information.

The SOA had also an overall influence on RTs, with increasingly slower responses as the SOA shortened. Here, the discriminability of prime and target could have also played a role, modulating the general disruption caused by the prime. The bigger temporal distance between prime and target for SOA = 300 as compared to SOA = 100 and 0 might lead to a higher degree of discriminability. Additionally, prime and target in the SOA = 300 condition were never simultaneously present on the screen, in contrast to the other SOA conditions. Thus, in the latter cases, participants had to make an extra effort to tell prime and target apart. Comparing SOA = 100 and 0 then, one would expect the SOA = 100 condition to offer better prime-target discriminability, since there is at least a small amount of temporal separation.

Finally, we also found that common gender words elicited fewer errors and faster responses than neuter gender words. Differences in word length were only marginal, with common gender words having on average 5.1 letters and neuter gender words 5.3 letters. The average lemma frequency (per million; CELEX Dutch database, 1990) for common gender words was 24.9 and 50.1 for neuter gender words. This goes against the direction of the effect in RT and accuracy, as higher frequency is usually associated with faster and more accurate performance. The gender effect might be a confound of the different sampling across the experimental session: The data entering the analysis came from all four blocks for common gender targets, but only from the first two blocks for neuter gender targets. By including measurements from the third and fourth block, the average RT for neuter gender targets decreases from 748 to 726 ms. Given a common gender average of 720 ms, the grammatical gender difference is reduced from 28 to 6 ms. Across the four blocks there seems to be a general practice effect at work, as RT steadily decreases – from first to fourth block, the averages for neuter gender targets are 761, 737, 707, and 700 ms, respectively. The averages for common gender targets are similar, showing only a small response speed advantage above neuter gender, which ranges from four to eight milliseconds across blocks. In summary, the gender effect found in the ANOVA on RTs is probably an artifact of excluding the neuter gender data of the last two blocks, which contained the fastest responses.

For the accuracy statistics, however, the picture is different. Including the neuter gender data from the third and fourth block has little influence. The average error percentage for neuter gender targets is 7.1 % when considering all blocks, only slightly less than the 8 % when considering the first two blocks only. Grammatical gender differences are bigger in the first two blocks (5.2 % and 3.5 %) than in the last two blocks (0.6 % and 2.3 %). One reason for this persistent difference could lie in the dominance of common gender nouns within the gender distribution of Dutch. Three quarter of Dutch nouns have common gender (Van Berkum, 1996), which could put them at a general advantage in gender decisions. It might also be the case, that gender classification for our particular set of common gender words was easier than for our set of neuter gender words. It is important to note, that irrespective of the different status of common and neuter gender words, both showed a gender congruity effect. This is indicated by the lack of an interaction between gender and congruity in the ANOVA.

We have demonstrated that a noun prime influences the gender access of a noun target, with gender congruent prime-target pairs showing faster responses than gender incongruent pairs. Our results contradict an account of gender access where the selection of a word automatically makes available the associated grammatical gender. In such a system, the gender congruity of primes would have no influence on the speed of gender access, since gender congruity would not influence word recognition.

Bates et al. (1996) have proposed a multidimensional vector space representation of words to explain gender congruity effects. The similarity of words corresponds to distance in vector space, such that words with the same properties (e.g., a particular grammatical gender) form clusters. A prime with the same grammatical gender as the target would push the system into the same direction as the target, towards the cluster corresponding to the shared gender. In contrast, a prime with different gender as the target would (momentarily) pull the system towards its own gender cluster, away from the gender cluster of the target. Bates et al. had originally suggested that gender priming be bound to situations where gender agreement plays a role. However, the noun-noun pairs for which we obtained priming are not subject to gender agreement in Dutch. In order to account for our findings, the vector space model would have to allow for gender priming which is independent of the establishment of gender agreement.

Another possibility to explain the gender congruity effect is offered by localist network models of the comprehension lexicon where a specific grammatical gender is represented by one node and gender selection depends on the activation of those nodes (analogous to Levelt et al., 1999). In such a system, a prime would activate its corresponding gender node, which can be identical to the target's gender node or different from it. With prime and target having identical gender, facilitatory priming would occur: Prime and target converge on the same gender node and contribute both to its activation level, so that selection takes place faster than in a situation without additional gender information. With prime and target having different gender, the prime would influence gender access in such a model only if there would be a competitive relation between the gender nodes. This could be implemented by way of inhibitory connections between gender nodes. Alternatively, selection of a gender node could depend on its relative activation strength with respect to the other gender node(s). In this case, a gender incongruent prime would make the competitor environment of the target's gender node stronger and thereby delay selection.

A localist computational model which offers the possibility to simulate gender access is WEAVER. As already mentioned, it has been developed to simulate speech production processes, but Levelt et al. (1999) assume that the conceptual and the lemma layer of WEAVER serve as well speech production as language comprehension (Roelofs, 1992, 2003; Roelofs et al., 1996; for a similar position regarding the lemma level see Branigan et al. 2000; Cleland & Pickering, 2003). Grammatical word properties, such as grammatical gender, are represented in the lemma layer. We ran some exploratory simulations to see whether WEAVER can capture our RT findings (details in Appendix). In WEAVER, the selection of a node depends on a production rule. Typically, such a production rule would check whether a node has reached a certain activation level, but also whether the node belongs to the target word. We considered three different production rules for gender selection. The most simple one checks that the gender node belongs to the target lemma and that the target lemma's activation exceeds the activation of all other candidate lemmas by a critical difference. The latter corresponds to the lemma being selected. Although this rule only refers to the activation of lemmas, the gender node activation by a congruent or incongruent prime still has an effect. This is so, because the expected selection time was computed as based on the ratio of the target gender's activation and the sum of the activation of both genders (Luce ratio, see Appendix). A gender congruent prime boosts the activation of the to be selected gender node (also increasing the overall activation by some amount), leading to faster selection. An incongruent prime contributes to the overall activation of all candidates, reflecting stronger competition and resulting in slower selection. The other two production rules contained the same conditions as the rule just mentioned, but had an additional condition which referred to the activation level of the gender nodes. In one rule, a gender node had to exceed an absolute activation threshold for selection to take place, without reference to the activation of the competing gender node. Congruent primes help reach this threshold faster (i.e. adding a facilitatory momentum), while incongruent primes have no consequences. In the other rule, a gender node had to exceed a relative threshold, that is, the gender node's activation had to be higher than the other gender node's activation by a certain amount. This implements extra competition (above the Luce ratio), that is, leading to facilitation on congruent trials and interference on incongruent trials. Simulating an experiment where primes occur in WEAVER further requires setting a parameter called distractor duration. It limits the time a prime (i.e., a distractor) is providing external input to the network, thereby capturing attentional processes which shut out the prime's influence after some time. We treated distractor duration and the gender-related threshold (for the last two production rules) as free parameters to fine-tune the model's performance with regard to the data.

The model without a gender threshold and the model with an absolute gender threshold both produced congruity effects which corresponded well to the data. A good fit is obtained for a distractor duration of 150 ms and – for the thresholded model – a gender threshold of 1.0 (see figure 3-2). The model with an absolute gender threshold delivered a good fit when the gender threshold was low and the distractor duration was high (i.e., 150 ms, 175 ms, or 200 ms). In these cases, the performance of the thresholded model actually equaled the performance of the model with no gender check. This might mean that the competition implemented through the Luce ratio is sufficient to explain the congruity effect we found in the gender decision task. The gender check with an absolute threshold did at least not further improve the correspondence of simulated and empirical data. The model with a relative gender threshold failed to capture the empirical results. It often produced exaggerated priming effects at SOA=100 and SOA=0 and also showed large differences between the priming effects for these SOAs, although empirically the effects had about the same size (23 and 21 ms, respectively).

The reason why WEAVER produces a gender congruity effect is the competitive mechanism implemented in the Luce ratio, taking into account the activation of the to be selected node and the sum of the activation of all candidate nodes. A gender congruent prime contributes to the activation of the target's gender node (and also to overall activation), which helps resolving competition earlier. An incongruent prime, on the other hand, strengthens the competitor environment and delays selection. Note that the inhibitory

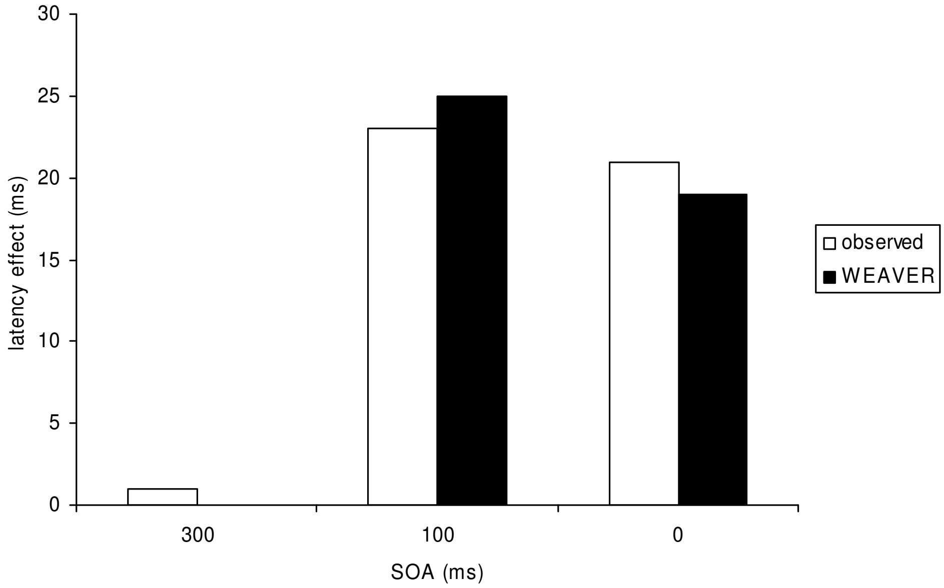

Figure 3-2. *Empirical and simulated latency effects of gender congruity at three SOAs. Simulated values correspond to a model with no gender threshold check as well as a model with an absolute gender threshold of 1.0, both run with a distractor duration of 150 ms.*

influence of incongruent primes in WEAVER is not related to strategic or controlled processes, but results from an automatic procedure which is necessary for selection.

In summary, we could show that the grammatical gender of a noun prime influences the gender access of a target noun as measured by gender decision. This is consistent with localist network models where nouns of identical gender share one gender node and gender selection depends on the activation levels of gender nodes. The implementation of one particular model, an adapted version of WEAVER (Roelofs, 1992, 2003; Levelt et al., 1999), was able to quantitatively capture the gender congruity effect from our experiment by using a simple competition mechanism. A vector space account of gender representation (Bates et al., 1996) also offers a viable explanation of the reported gender congruity effect. In contrast, localist network models where gender access is an automatic consequence of word recognition can not explain our results.

References

Bates, E., Devescovi, A., Hernandez, A., & Pizzamiglio, L. (1996). Gender priming in Italian. *Perception & Psychophysics, 58*, 992-1004.

Bates, E., & MacWhinney, B. (1989). Functionalism and the competition model. In B. MacWhinney & E. Bates. (Eds.), *The cross-linguistic study of sentence processing* (pp. 3-73). New York: Cambridge University Press.

Branigan, H.P., Pickering, M.J., & Cleland, A.A. (2000). Syntactic co-ordination in dialogue. *Cognition, 75*, B13-B25.

CELEX Dutch database (Release N31) [On-line]. (1990). Available at: http://www.mpi.nl/world/celex

Cleland, A.A., & Pickering, M.J. (2003). The use of lexical and syntactic information in language production: Evidence from the priming of noun-phrase structure. *Journal of Memory and Language, 49*, 214-230.

Corbett, G.G. (1991). *Gender*. Cambridge: Cambridge University Press.

Dell, G.S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review, 93*, 283-321.

Desrochers, A. (1986). Grammatical gender and noun classification. *Canadian Journal of Psychology-Revue Canadienne De Psychologie, 40*, 224-250.

Deutsch, A., & Bentin, S. (2001). Syntactic and semantic factors in processing gender agreement in Hebrew: Evidence from ERPs and eye movements. *Journal of Memory and Language, 45*, 200-224.

Deutsch, W., & Wijnen, F. (1985). The article's noun and the noun's article: Explorations into the representation and access of linguistic gender in Dutch. *Linguistics, 23*, 793-810.

Elman, J.L. (1990). Finding structure in time. *Cognitive Science, 14*, 179-211.

Elman, J.L. (1993). Learning and development in neural networks: The importance of starting small. *Cognition, 48*, 71-99.

Friederici, A.D. (1995). The time course of syntactic activation during language processing: A model based on neuropsychological and neurophysiological data. *Brain and Language, 50,* 259-281.

Friederici, A.D. (2002). Towards a neural basis of auditory sentence processing. *Trends in Cognitive Sciences, 6,* 78-84.

Friederici, A.D., & Jacobsen, T. (1999). Processing grammatical gender during language comprehension. *Journal of Psycholinguistic Research, 28*, 467-484.

Grosjean, F., Dommergues, J.Y., Cornu, E., Guillelmon, D., & Besson, C. (1994). The gender-marking effect in spoken word recognition. *Perception & Psychophysics, 56*, 590-598.

Gunter, T.C., Friederici, A.D., & Schriefers, H. (2000). Syntactic gender and semantic expectancy: ERPs reveal early autonomy and late interaction. *Journal of Cognitive Neuroscience, 12*, 556-568.

Hagoort, P., & Brown, C.M. (1999). Gender electrified: ERP evidence on the syntactic nature of gender processing. *Journal of Psycholinguistic Research, 28*, 715-728.

Hagoort, P., Brown, C.M., & Osterhout, L. (1999). The neurocognition of syntactic processing. In C.M. Brown & P. Hagoort (Eds.), *The neurocognition of language* (pp. 273-316). Oxford: Oxford University Press.

Harley, T.A. (1993). Phonological activation of semantic competitors during lexical access in speech production. *Language and Cognitive Processes, 8,* 291-309.

Kempen, G., & Hoenkamp, E. (1987). An incremental procedural grammar for sentence formulation. *Cognitive Science, 11*, 201-258.

Levelt, W.J.M. (1989). *Speaking: From intention to articulation*.Cambridge, MA: MIT Press

Levelt, W.J.M., Roelofs, A., & Meyer, A.S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences, 22,* 1-75.

Luce, R.D. (1959). *Individual choice behavior*. New York: Wiley.

McRae, K., Ferretti, T.R., & Amyote, L. (1997). Thematic roles as verb-specific concepts. *Language and Cognitive Processes, 12*, 137-176.

Nicol, J.L., Forster, K.I., & Veres, C. (1997). Subject-verb agreement processes in comprehension. *Journal of Memory and Language, 36*, 569-587.

Osterhout, L., McLaughlin, J., & Bersick, M. (1997). Event-related brain potentials and human language. *Trends in Cognitive Sciences, 1*, 203-209.

Pearlmutter, N. J., Garnsey, S. M., & Bock, K. (1999). Agreement processes in sentence comprehension. Journal of Memory and Language, 41, 427-456.

Radeau, M., & Van Berkum, J.J.A. (1996). Gender decision. *Language and Cognitive Processes, 11*, 605-610.

Roelofs, A. (1992). A spreading-activation theory of lemma retrieval in speaking. *Cognition, 42,* 107-142.

Roelofs, A. (2003). Goal-referenced selection of verbal action: Modelling attentional control in the Stroop task. *Psychological Review, 110*, 88-125.

Roelofs, A., Meyer, A.S., & Levelt, W.J.M. (1996). Interaction between semantic and orthographic factors in conceptually driven naming: Comment on Starreveld and La Heij (1995). *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 246-251.

Roelofs, A., Meyer, A.S., & Levelt, W.J.M. (1998). A case for the lemma/lexeme distinction in models of speaking: Comment on Caramazza and Miozzo (1997). *Cognition, 69*, 219-230.

Spinelli, E., & Alario, F. X. (2002). Gender context effects on homophone words. *Language and Cognitive Processes, 17*, 457-469.

Stemberger, J.P. (1985). An interactive activation model of language production. In A.W. Ellis (Ed.), *Progress in the psychology of language, Vol. 1* (pp. 143-186). London: Erlbaum.

Tanenhaus, M.K., Dell, G.S., & Carlson, G. (1987). Context effects and lexical processing: A connectionist approach to modularity. In J. L. Garfield (Ed.), *Modularity in* *knowledge representation and natural-language processing* (pp. 83-108). Cambridge, MA: MIT Press.

Taraban, R., & McClelland, J.L. (1988). Constituent attachment and thematic role assignment in sentence processing: Influences of content-based expectations. *Journal of Memory and Language, 27*, 597-632.

Van Berkum, J.J.A. (1996). *The psycholinguistics of grammatical gender: Studies in language comprehension and production*. Nijmegen: Nijmegen University Press.

Appendix

Details of the WEAVER Simulations

WEAVER is a hybrid model, combining a spreading activation mechanism with a production rule system, which is involved in selection processes. The network consists of nodes representing word properties, with their activation level depending on the input from adjacent nodes or an external stimulus. In case of a visually presented word, the respective lemma node receives a fixed amount of external input. The lemma in turn sends activation to the respective gender and concept node (see Roelofs, 1992, 2003; Roelofs et al., 1996). From the concept node, activation can spread further to semantically related concepts. The connections from lemmas to gender nodes are unidirectional, whereas the connections between lemmas and concepts as well as among concepts are bidirectional. Activation spreads according to the following formula:

$$a(m, t + \Delta t) = a(m, t)(1 - d) + \sum_n r a(n, t) \, .$$

a(m, t) denotes the activation of node *m* at time *t*. *d* is the decay rate, and *Δt* is the duration of a time step in ms. The rightmost expression represents the amount of activation *m* receives from other nodes (indexed as *n*), dependent on their respective activation level and the weighting by spreading rate *r*.

The selection of particular nodes depends on production rules. Typically, such a production rule would check whether a node has reached a certain activation level, but also whether the node belongs to the target word. The activation of competing nodes can influence the speed of selection in two ways. One way is to explicitly check via the production rule whether the activation of a particular node exceeds the activation of the other candidate nodes by a critical difference (as is the case for the production rule selecting lemmas, see Roelofs, 1992). The second way lies in the computation of the actual selection time, which depends on the ratio of the activation of the target node *m* and the sum of activation of all candidate nodes (indexed *k*), the Luce ratio (cf. Luce, 1959).

$$p(\text{selection at } t < \mathrm{T} \leq (t + \Delta t) \mid \text{no selection of } m \text{ at } \mathrm{T} \leq t) = \frac{a(m,t)}{\sum_k a(k,t)} \, .$$

It gives the probability that a target node *m* will be selected at $t < \mathrm{T} \leq (t + \Delta t)$, given that *m* has not been selected at $\mathrm{T} \leq t$ and that the conditions for its selection are met. With increasing activation of the candidate nodes the ratio becomes smaller, reflecting a competitive mechanism. The Luce ratio corresponds to the hazard rate *h(s)* of a retrieval process at time step *s*, with $t = (s\text{-}1)\ \Delta t$, and $s = 1, 2, ...$ This hazard rate forms part of a formula which gives the expected selection time (derivation in Roelofs, 1992):

$$E(T) = \sum_{s=1}^{\infty} \left[h(s) \prod_{j=0}^{s-1} \left[1 - h(j)\right] s\Delta t \right].$$

By the inclusion of the hazard rate the computation of selection times is also reflecting competition among nodes.

In our simulations we used a small network with eight words, half of them carrying common gender and half of them carrying neuter gender. We computed expected selection times for gender congruent and gender incongruent prime-target pairs, with SOAs of 0, 100, and 300 ms. The critical difference for lemma selection was set to 3.0, like in the simulation for experiment 3 in Roelofs (2003), where participants saw a written noun and had to produce the definite article and the noun. For the remaining parameters, we used the same values which Roelofs (1992) has established and used in a wide range of simulations:

Spreading rate conceptual level, r_c: 0.0101 ms^{-1}.
Spreading rate lemma level, r_l: 0.0074 ms^{-1}.
Decay rate, d: 0.0240 ms^{-1}.
External input, *extin*: 0.1965 activation units ms^{-1}.
Duration of a time step, Δt: 25ms.

PRIMING THE RETRIEVAL OF GRAMMATICAL GENDER: AN ERP STUDY

Chapter 4

Oliver Müller and Peter Hagoort (submitted)

Abstract

Studies using event-related potentials have found evidence that in language comprehension semantic category is retrieved before grammatical gender when words are presented in isolation. We investigated whether speeding up gender retrieval by means of gender-congruent primes could reverse that retrieval order. In a two-choice go/nogo task, with gender determining response hand and semantic category determining the go/nogo decision, a transitory nogo LRP occurred in the gender-congruent condition. This indicates that hand-specific response preparation based on gender took place before inhibition based on semantics set in. Such a reversal of retrieval order implies a parallel rather than a serial discrete arrangement of the two retrieval processes, since the latter variant precludes changes in retrieval order. The N2 effect, reflecting more negative activity on nogo than go trials, showed an influence of gender congruity, although the go/nogo decision depended on semantic category. This points towards a general sensitivity of the N2 effect for task aspects engaging inhibition or conflict monitoring.

Introduction

Language comprehension begins with the perception of auditory or visual stimuli and reaches its goal with the (re)construction of a meaningful message. One important step in this transformation is the retrieval of semantic and syntactic word properties in the course of word recognition. They provide the informational bits and pieces for assembling a complex and encompassing representation of an utterance or text. Semantic word properties serve as building blocks for the overall meaning, but can also contribute to the formation of syntactic structures (e.g., McRae, Ferretti, & Amyote, 1997). The syntactic properties of words provide information on how words relate to each other, which is used in the formation of syntactic structures and in morphological processes.

In order to shed light on the details of accessing semantic and syntactic word properties, we had investigated the relative time course of their retrieval in a previous study using event-related potentials (ERPs; chapter 2 of this thesis). We presented Dutch nouns in their written form and contrasted the retrieval of semantic category (e.g., building or consumable) and grammatical gender. The grammatical gender of nouns is a syntactic word property occurring in a wide range of languages (cf. Corbett, 1991). It is involved in a morphosyntactic process called gender agreement, which determines the form of articles and adjectives, among others. The Dutch language distinguishes two grammatical genders, labeled common and neuter gender (cf. Van Berkum, 1996). The design of the study followed the example of Van Turennout, Hagoort, and Brown (1997), with participants performing a two-choice go/nogo task. The instructions in our study stated that a particular semantic category corresponded to a left hand response and another category to a right hand response. However, participants had to execute the response only if the word had a particular gender (go), and had to withhold the response if it had the other gender (nogo). From electroencephalographic recordings above motor cortex we computed the lateralized readiness potential (LRP), an index of hand-specific movement preparation (De Jong, Wierda, Mulder, & Mulder, 1988; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988). Crucially, we could observe transitory LRP activity in the nogo condition, which receded before triggering an overt response. Since LRP activity indicates movement preparation for a specific hand and response hand depended on semantic category, semantic information must have been available before response inhibition set in, which depended on gender information. This suggests that semantic category was available before grammatical gender. However, there was a possible strategic explanation. Participants could have given priority to the processing of response hand information (i.e., semantic category) over the processing of go/nogo information, in order to maximize response preparation and thereby response speed (cf. Smid, Mulder, Mulder, & Brands, 1992). In that case, a nogo LRP should occur regardless of which word properties determine response hand and response execution. To check this, we devised a task with reversed instructions, so that gender determined response hand and semantic category determined response execution. This time, we found no LRP activity in the nogo condition, which contradicts the strategic account and is in line with semantic category being retrieved before gender: Semantic information could establish the nogo status of a trial before gender would lead to response preparation.

We also inspected a frontal N2 effect, which Schmitt, Münte, and Kutas (2000) have introduced to the monitoring of time courses in language processing. This N2 effect is found in go/nogo tasks, with a negative peak having a bigger amplitude for nogo trials than for go trials. It is commonly assumed to reflect response inhibition (Eimer, 1993; Falkenstein, Hoormann, & Hohnsbein, 1999; Jodo & Kayama, 1992; Kok, 1986). In our study (chapter 2), we compared the timing of the N2 effect for the tasks in which semantic category and gender determined the go/nogo decision. Both onset and peak latencies of the N2 effect showed a temporal advantage for semantic category, confirming that semantic information is available earlier than syntactic information. Furthermore, Schmitt, Rodriguez-Fornells, Kutas, and Münte (2001) conducted a comparable study with auditorily presented words in German, also finding an earlier N2 effect for semantics than for gender.

The aim of the current study is to explore how far the retrieval of semantic and syntactic word properties in language comprehension is open to the influence of context. Both our earlier study (chapter 2) and the study of Schmitt, Rodriguez-Fornells et al. (2001) used words presented in isolation. However, the presence of other language stimuli might create a context which influences the timing of retrieval, that is, the retrieval of certain word properties could be primed. Priming of gender retrieval might even lead to gender being available earlier than semantic category. Gender-related contexts have been used to investigate the influence of advance gender information on word recognition (for a review, see Friederici & Jacobsen, 1999). In a typical experiment, a gender-marked prime word precedes a noun target with congruent or incongruent gender and participants perform a lexical decision or naming task on the target to tap into word recognition processes. For our purposes, however, it is important to assess the impact of a gender-related context on gender retrieval itself. In our earlier ERP study and the study of Schmitt, Rodriguez-Fornells et al., gender retrieval was probed by a gender decision task (Radeau & Van Berkum, 1996). Bates, Devescovi, Hernandez, and Pizzamiglio (1996) used this task (labeling it gender monitoring) in a study with auditorily presented Italian adjective-noun pairs. Adjectives carried a gender-neutral suffix or a gender-marking suffix, with the latter being either congruent or incongruent with the noun's gender. Gender decisions on the noun were faster for gender-congruent and gender-neutral adjectives than for gender-incongruent adjectives. One possible problem is that a gender-incongruent adjective-noun pair forms an ungrammatical noun phrase. The effect, therefore, could be based on a grammaticality judgment. Furthermore, there is an issue of co-occurrence statistics, since in natural situations nouns mostly co-occur with the gender-congruent adjective suffix (cf. Dahan, Swingley, Tanenhaus, & Magnuson, 2000). This form-related bias could have influenced gender decision times, whereas we are interested in the lexical retrieval of gender.

To explore the possibility of priming gender retrieval, we conducted a gender decision experiment with written stimuli in Dutch (chapter 3 of this thesis). Both primes and targets were nouns, and particular pairs had identical or different gender (i.e., they were gender-congruent or gender-incongruent). Crucially, noun-noun pairs do not underlie gender agreement and, therefore, show no gender-related co-occurrence statistics. Additionally, we tested prime-target SOAs of 300, 100, and 0 ms. Responses in the SOA=100 and SOA=0 conditions were significantly faster for gender-congruent than gender-incongruent pairs, by about 20 ms. At SOA=300 there was virtually no difference between the gender-congruent and -incongruent condition. This was presumably due to the decay of prime activation or the more effective suppression of prime information as compared to the short SOAs, where the discriminability of prime and target might have been lower. In summary, the experiment provided evidence for the priming of gender retrieval at short SOAs.

Taking the priming of gender decisions as a starting point, we devised an experiment to manipulate the relative time course of semantic category and gender retrieval in language comprehension. As already mentioned, previous studies found evidence that semantic category is available earlier than grammatical gender (see chapter 2; Schmitt, Rodriguez-Fornells et al., 2001). We used the same material as in chapter 3 and combined words into gender-congruent and -incongruent pairs, aiming for an accelerated retrieval of gender, thereby making gender available earlier than semantic category. This was combined with a two-choice go/nogo task and the recording of LRP activity to measure the time course of retrieval. Grammatical gender determined response hand and semantic category determined response execution (go/nogo).

The issue of manipulating the retrieval order for gender and semantic category is linked to the question whether the retrieval of the two word properties occurs in a serial discrete or in a parallel manner. If retrieval takes place in a series of discrete stages, so that a stage only starts when the previous one has finished, gender priming can speed up gender retrieval itself but it can not change the retrieval order in relation to semantics. In a parallel arrangement, however, the retrieval processes for the two word properties are independent and their relative time course can be changed by speeding up or delaying one of the processes. In the following paragraphs, we list the predictions regarding the effects of gender congruity that follow from a serial discrete and a parallel architecture.

Concerning overt responses, one has to consider that both semantic category and gender are necessary to produce a correct response. In case of a serial discrete architecture, processing time differences at the independent stages would contribute to RT in an additive manner. Accordingly, the gender congruity effect observed for simple gender decisions (see chapter 3) should also appear in the two-choice go/nogo task. The outcome of a parallel architecture depends on how much gender-congruent primes speed up gender retrieval – making it faster than semantic retrieval or leaving it to be slower still. In the former case, we expect the priming effect found in the simple decision task to be reduced in the two-choice go/nogo task, following considerations of Abdel Rahman (Abdel Rahman, 2001, exp. 2 and 3; Abdel Rahman, Sommer, & Schweinberger, 2002). In the two-choice go/nogo task, the launch of an overt response has to wait until the slowest necessary information becomes available. If gender-congruent primes make gender available before semantic category, there is a waiting period for semantics, which absorbs part of the gender priming effect and makes it invisible to RT measures. If gender retrieval is not faster than semantic retrieval in the congruent condition, there is no such absorption and RT should display a gender priming effect as for the simple gender decision. Thus, a reduction of the gender priming effect for RT would be evidence for a parallel architecture, where additionally gender retrieval is faster than semantic retrieval in the gender-congruent condition. An unreduced gender priming effect for RT would be consistent with both a serial discrete and a parallel architecture.

The onset of the go LRP indicates the start of hand-specific response preparation, which depends on gender retrieval in our experiment. Both a serial discrete and a parallel arrangement allow for the speeding up of gender retrieval by gender-congruent primes. Therefore, both alternatives predict an earlier onset of the go LRP for the gender-congruent than the gender-incongruent condition.

Regarding the occurrence of a nogo LRP, serial discrete and parallel arrangements make different predictions. A serial discrete arrangement is defined by a fixed order of retrieval, that is, uniformly gender before semantics or semantics before gender. The former order is implausible, as previous ERP studies found evidence that semantic category is available earlier than grammatical gender for words presented in isolation (chapter 2; Schmitt, Rodriguez-Fornells et al., 2001). As for a serial discrete architecture with semantics being retrieved before gender, the nogo information (derived form semantics) would always be available before respond hand information, precluding the occurrence of a nogo LRP. In contrast, a parallel arrangement places no such restrictions. Given that gender-congruent primes speed up gender retrieval sufficiently to make gender available before semantic category, hand-specific motor preparation could start before the nogo status of a trial is established. This would then become visible as LRP activity on nogo trials in the gender-congruent condition.

All preceding considerations of the LRP have dealt with the time from stimulus presentation to onset of lateralized motor activity, that is, with the stimulus-locked LRP. We will also compute the response-locked LRP, taking RT as temporal reference point. This will gain data on the time from LRP onset to actual response. Abdel Rahman et al. (2002; see also Abdel Rahman & Sommer, 2003) have used the onset-to-response interval of the LRP to distinguish between a serial discrete and a parallel architecture in retrieving two features during face recognition. Crucial for the underlying rationale is that the LRP is supposed to start up when information about the required response hand comes in, while the final steps of response execution, immediately preceding the overt response, can be initiated only when the go status of a trial is established. The length of the onset-to-response interval then depends on the time which passes between the left/right and the go/nogo decision (given the final processes related to response execution have a constant duration across conditions). Regarding the current study, a serial architecture with semantic before gender retrieval would provide the go status before the required response hand. Therefore, the stage of hand-specific response preparation could be seamlessly followed by the final motor processes. However, in a parallel architecture speeding up gender retrieval would affect the onset-to-response interval. If gender is available before semantic category in the congruent condition, hand-specific response preparation could begin while the final processes involved in response execution would be stalled until semantic information is available. In the incongruent condition gender retrieval should take longer than in the congruent condition and given the duration of semantic retrieval stays constant, the time between the left/right and the go/nogo decision would be shorter. Accordingly, the incongruent condition would have a shorter onset-to-response interval than the congruent condition.

Several studies investigating the time course of language processing utilized a frontal N2 effect occurring in go/nogo tasks, thought to be related to response inhibition (e.g. Schmitt et al., 2000; Schmitt, Rodriguez-Fornells et al., 2001). In the present study, however, the experimental manipulation applied only to the word property associated with response hand, that is, grammatical gender. Nonetheless, one might speculate that an incongruent prime as such engages the inhibitory system in a different way as a congruent prime. An incongruent prime is by definition more different from the target than a congruent prime, leading to more activation which is irrelevant for correct performance, so that more effort might be allocated to suppress irrelevant activation. Furthermore, some researchers have recently proposed that the N2 effect reflects conflict monitoring rather than inhibition (Donkers & Van Boxtel, 2004; Nieuwenhuis, Yeung, Van der Wildenberg, & Ridderinkhof, 2003). Under this view, one might assume that an incongruent prime generates more conflict than a congruent one, which could lead to a modulation of the N2 effect. Given that the N2 effect might reveal aspects of executive functioning regarding our task, such as inhibition or conflict monitoring, we will include N2 analyses in our results section.

Regarding the timing of prime and target presentation, we chose an SOA of 100 ms. In the experiment from chapter 3, the priming effect was about 20 ms for both SOA= 100 and 0. Simple effects analyses for the two SOAs concerning gender congruity, however, produced a higher t value for SOA=100 than 0, indicating a stronger effect for SOA=100.

Method

Participants

Sixteen native speakers of Dutch (three male) took part in the experiment, with age being on average 21.3 years and ranging from 18 to 27 years. None of them had participated in the paper-and-pencil-test or the behavioral gender priming experiment (chapter 3). All participants were right-handed and had normal or corrected-to-normal vision. None of them had any neurological impairment, had experienced neurological traumas or used neuroleptics. They were paid for participation in the experiment.

Materials

Words from 12 different semantic categories made up the set of experimental stimuli: building, consumable, landscape formation, animal, part of a house, clothing, weapon, body part, kitchen utensil, vehicle, furniture, and plant. Words from the first 8 categories had been used in an earlier study and had proven to be consistently classified regarding their semantic category and grammatical gender (chapter 2). To select consistently classifiable words from the last four categories, we carried out a paper-and-pencil test. Thirty participants received a randomized word list and had to decide whether a word was of common or neuter gender and to which of the four mentioned semantic categories it belonged. The selection procedure resulted in 192 critical words, with eight category lists having 18 members and four lists having 12 members. Each category list comprised one third neuter gender items and two third common gender items. The semantic categories were arranged into pairings, to allow for binary decisions in the semantic classification. Every category was combined with two other categories, resulting in 12 category pairings (see table 4-1). We made sure that the distributions of word length in letters and lemma frequency in a given category pairing substantially overlapped for the two semantic categories and the words of common and neuter gender. Words from the categories musical instrument and stationery were used for extra practice blocks.

Procedure

Participants were tested in an electrically shielded and dimly lit room, which was separated by a sound-attenuating door from the experimenter's room. They sat in a reclining chair, facing a computer screen. The left and right index finger was placed on push-buttons, inserted in the arm rests of the chair.

A trial started with the presentation of an asterisk in the middle of the screen, for 1500 ms. During the last 200 ms a rectangular frame surrounded the asterisk. Then the screen turned blank for 1000 ms. Subsequently, the prime, in lower case letters, appeared at a position above or below the middle of the screen. After 100 ms the target, presented in upper case letters, appeared at the complementary position above or below the centre of the screen.

Table 4-1. *The 12 Semantic Category Pairings Used in the Experiment*

1.	buildings	vs.	consumable
2.	buildings	vs.	animals
3.	landscape	vs.	consumable
4.	landscape	vs.	animals
5.	parts of a house	vs.	clothing
6.	parts of a house	vs.	body parts
7.	weapons	vs.	clothing
8.	weapons	vs.	body parts
9.	kitchen utensils	vs.	vehicles
10.	kitchen utensils	vs.	plants
11.	furniture	vs.	vehicles
12.	furniture	vs.	plants

Prime and target stayed on the screen for 1000 ms, then the screen turned blank for another 1000 ms and a new trial began. Words were presented in white Arial letters against dark background. Viewing distance was approximately 100 cm, the horizontal visual angle for the longest word was about 3.1° and the vertical visual angle for a prime-target pair was maximally 1.7°.

The experimenter asked participants to keep their arms relaxed and not to blink or move their eyes, except for the period when the asterisk was on the screen. The appearance of the frame around the asterisk informed participants that the rest period was about to end. Participants had to perform a two choice go/nogo task, in which the target's grammatical gender determined response hand (left/right) and its semantic category determined response execution (go/nogo). The instruction informed participants that only words in upper case letters were relevant to the task and that words in lower case letter had to be ignored and would appear somewhat earlier than the targets.

A session consisted of 24 experimental blocks, each comprising material from one of the category pairings (see table 4-1). Every six blocks, the left/right assignment for grammatical gender changed. Within such a series of six blocks, all 12 semantic categories occurred once. The specific category pairing in which a category appeared changed for consecutive occurrences (e.g., first *building vs. consumable*, then *building vs. animal*). The mapping of a semantic category onto the go/nogo decision was constant for a given participant, while it was counter-balanced across participants. At the start of a session and after changes of left/right assignment, participants received 32 practice trials from extra categories. Every experimental block was additionally preceded by 16 practice trials with extra items from the respective semantic categories.

As indicated in the materials section, we had selected twice as many words of common gender than of neuter gender. This served the purpose of employing as many different words as possible, allowing us to run a large number of critical trials without many repetitions per word. Nonetheless, we wanted an equal amount of common and neuter gender words in an experimental block. Therefore, the materials for an experimental block comprised all neuter gender words from the involved semantic categories, but only half of the common gender words from each category. The complete set of common gender words from a semantic category appeared across the first and second block containing the respective category and again across the third and fourth block. Each word within an experimental block occurred once as target and once as prime. In the course of a session, common gender words appeared twice as target and neuter gender words four times. Only the first two presentations of neuter gender targets were considered for analysis.

The assignment of primes to targets was pseudorandomized, with the restriction that prime and target originated from opposite categories within a block. We made sure that there was no prime-target pair where the words shared the onset, rhymed, or had a semantic or associative relationship. Within an experimental block, two words were combined only once in a prime-target pair. Furthermore, half of the targets from a particular category-gender combination (e.g., *building – common gender*) occurred with a gender-congruent prime and the other half with a gender-incongruent prime. Targets from a congruent prime-target pair appeared in an incongruent pair during the next presentation as a target, and vice versa. The target position (upper/lower) was pseudorandomized. Within a block targets from a given category-gender combination occurred equally often at the upper and the lower position. The trial order of prime-target pairs was pseudorandomized with the restrictions that the same target position, target gender, and target semantic category occurred no more than three times in a row and that at least one trial intervened before a word from a prime-target pair was presented again. A block could last up to four minutes and the whole session took approximately three and a half hour.

Electrophysiological Recordings

The EEG was recorded at 17 sites on the scalp, with reference to the left mastoid. These sites represent a selection of electrode slots in the Easy-Cap Montage No. 10 as provided by Falk Minow Services (for theta/phi coordinates see: Theta/phi-coordinates of equidistant montage no. 10, n.d.). The five midline sites with the numbers 35, 20, 2, 1, 14, and 43 correspond to the positions AFz, FCz, Cz, Pz, and Oz of the 10%-system of the American

Electroencephalographic Society (1991). The remaining electrodes were placed laterally over symmetrical positions: frontal (in pairs of corresponding electrodes: 33, 22; 34, 21), fronto-central (18, 10; 7, 3), and occipital (45, 41; 44, 42). For the computation of the LRP we used the lateral fronto-central electrodes. Electrode pair 18/10 was approximately 6 cm lateral and 3 cm anterior to Cz, while electrode pair 7/3 was approximately 3 cm lateral and 2 cm anterior to Cz. In order to control the quality of the left mastoid as neutral reference, an additional electrode was attached to the right mastoid, referenced to the left mastoid. A ground electrode was placed on the forehead. Blinks and vertical eye movements were recorded bipolarly using electrodes situated above and below the left eye. Horizontal eye movements were monitored via a bipolar montage of electrodes positioned external to the left and right outer canthus of each eye. The electromyogram (EMG) of the left and right forearm flexors was recorded bipolarly with electrodes placed following the recommendations of Lippold (1967). Ag/AgCl electrodes were used for all recordings. Electrode impedance was kept below 3kΩ for the EEG recording, below 5 kΩ for the electrooculogram (EOG) recording, and below 10 kΩ for the EMG recording. The signals were amplified by a BrainAmp amplifier and data acquisition occurred via VisionRecorder. For all recordings a time constant of 10s was set. The high-frequency cutoff was 30 Hz for EEG and EOG recordings and 100 Hz for the EMG recording. Digitization of the signals took place on-line with a sampling frequency of 500 Hz. Sampling was continuous.

Data Analysis

Overt responses. The following events were marked as errors: A nogo trial where a push-button response was registered; a go trial with a push-button response on the wrong side or no response within 1600 ms after appearance of the prime. Trials containing an error were excluded from the RT and ERP analyses.

Event-related potentials. For the stimulus-locked analysis (LRP and N2 effect), we extracted sweeps starting 150 ms before prime onset and ending 1600 ms after prime onset. The 150 ms period before prime onset served as baseline and we subtracted its average voltage per trial and electrode from the respective waveforms. The response-locked analysis for the LRP (only go trials) employed the RT of the trial as alignment point. Sweeps from 1750 ms before response to 200 ms after response were extracted, with baseline correction taking place on the basis of the period from 1750 to 1600 ms before response. Artifact control occurred for stimulus- and response-locked analysis separately. We marked sweeps containing eye movement artifacts, amplifier blocking, or an amplitude of 75 µV above or below baseline. We also inspected the EMG (stimulus- and response-locked) for any activity on nogo trials and activity of the wrong response hand on go trials. Sweeps with artifacts or inappropriate EMG activity were excluded from the respective ERP analyses. Trials with ERP artifacts or inappropriate EMG activity in the stimulus-locked data were also excluded from RT and accuracy analyses.

We computed stimulus-locked and response-locked LRPs for the electrode pairs 18/10 and 7/3. This was done for both gender congruity conditions, separately for the go and nogo condition. To test for correct preparatory motor activity in the LRP, we performed series of t-tests on voltage amplitude. First, moving averages of voltage were computed for all subject LRPs, with a window width of 50 ms. For the stimulus-locked LRPs, the first window started at 6 ms and ended at 54 ms after prime onset, having its center at 30 ms. The next window was shifted in time by 10 ms, having its center at 40 ms and so forth. The last window had its center at 1000 ms after stimulus onset. For every window a two-tailed t-test against zero was performed on the moving averages. If five consecutive windows had a p-value < .05, we assumed that a meaningful deviation from baseline had occurred. The centre of the first significant window counted as onset latency of such activations. For the response-locked LRPs, the first window started at -1594 ms and ended at -1544 ms before RT, having its center at -1570 ms. The following windows were all shifted by 10 ms, with the last window having its center at 10 ms after RT. Otherwise, the testing procedure was equivalent to the one described for stimulus-locked LRPs. In case of meaningful nogo activity in the stimulus-locked LRP developing in parallel with go activity, we also tested for the point where nogo and go waveform would finally diverge. This point in time, where the go waveform continues to rise and the nogo waveform begins its return to baseline, signifies the moment when inhibitory information is available and forces the abortion of further motor preparation (cf. Osman, Bashore, Coles, Donchin, & Meyer, 1992). We applied two-tailed paired-samples t-tests to the moving averages of the go and nogo waveforms. If five consecutive windows showed a significant difference (later than the onset of nogo activity), we regarded the first of these windows as the point of divergence.

To investigate the N2 effect we first computed subject averages of go and nogo trials, separately for the two gender congruity conditions. Then we subtracted the go average from the respective nogo average in order to get the net effect. We determined the onset latency of this effect for a combined average of all five frontal electrodes, using the same serial t-test technique described for the stimulus-locked LRP. Additionally, we determined the peak latency of the N2 effect by searching for the largest negative voltage value within a time window from 400 to 700 ms after stimulus onset, separately for all five frontal electrodes.

Results

All following analyses include only data from the first two presentations of a target word, unless stated otherwise.

Overt Responses

We report RT in relation to the moment of prime presentation to allow comparison with the ERP data, where prime onset corresponds to time zero. The RT averaged over participants was 960 ms in the gender-congruent condition and 966 ms in the gender-incongruent condition. We ran a univariate ANOVA including the two within-participants factors Gender Congruity and Target Gender. Gender congruity produced no significant main effect ($F(1,15) = 2.1$, $MSE = 273.4$, $p = .164$), whereas target gender did ($F(1,15) = 18.8$, $MSE = 1810.0$, $p = .001$). Common gender targets displayed faster responses (940 ms) than neuter gender targets (986 ms).

We treat behavioral errors on go and nogo trials in separate analyses, since different error categories apply to go trials (response with incorrect hand and timeout) and nogo trials (any overt response). For both trial types, we performed a univariate two-way ANOVA, with the within-participants factors Gender Congruity and Target Gender. For go trials, the average percentage of errors was 8.3 % for gender-congruent trials and 8.1 % for incongruent trials. The main effect of Gender Congruity was not significant ($F < 1$), whereas the main effect of Target Gender was ($F(1,15) = 7.8$, $MSE = 37.7$, $p = .014$), reflecting a higher error percentage for neuter gender targets (10.3 %) than common gender targets (6.1 %). The interaction of gender congruity and target gender was not significant ($F(1,15) = 1.9$, $MSE = 13.8$, $p = .187$). In case of nogo trials, gender-congruent trials showed on average 0.9 % errors and gender-incongruent trials 1.0 % errors. The main effects of Gender Congruity and Target Gender failed to reach significance (Fs < 1), as did the interaction ($F(1,15) = 1.1$, $MSE = 2.7$, $p = .322$).

We decided to run more detailed analyses on RT and go trial errors, since the Target Gender effects we found might be an artifact of the different sampling of neuter and common gender words: The first two presentations of neuter gender words already occurred in the first half of the experiment, whereas the first two presentations of common gender words were distributed across the whole length of the experiment. Thus, common gender trials from the second half of the experiment might have benefited from additional task practice. In order to check this, we performed ANOVAs including all presentations of common and neuter gender words, with the within-participants factors Gender Congruity, Target Gender, and Quarter. The latter divides the experimental session in consecutive quarters of six blocks, with each quarter containing the whole set of neuter gender words (quarter 1 and 2 contain the whole set of common gender words, quarter 3 and 4 contain the repetition of this set). By including this factor we should be able to track changes due to task practice.

In the new RT analysis, the main effect of Target Gender was not significant ($F(1,15) = 1.6$, $MSE = 5650.9$, $p = .223$). However, the main effect of Quarter was significant ($F(3,45) = 9.1$, $MSE = 7546.3$, $p < .001$, $\varepsilon = .836$ [1]), as well as the interaction of target gender and

1. We used the univariate approach to ANOVAs and corrected violations of sphericity for repeated measures factors by adjusting *df*s with the Greenhouse-Geisser epsilon. When applicable, we report the uncorrected *df*s and *MSE*, followed by the corrected *p* value and the ε value.

quarter ($F(3,45) = 5.6$, $MSE = 1414.3$, $p = .003$, $\varepsilon = .897$). A simple effects analysis of the factor Target Gender under the levels of quarter indicated that in the second quarter, common gender words elicited faster responses than neuter gender words (940 ms vs. 976 ms; $t(15) = -2.7$, $SE = 13.8$, $p = .018$, not corrected for multiple comparisons). The new analysis on go trial errors showed a significant main effect of Target Gender ($F(1,15) = 11.1$, $MSE = 53.9$, $p = .004$), while no other main effects or interactions were significant.

Stimulus-locked LRP

Time zero refers to the onset of the prime, with target presentation at 100 ms. We will first treat the results for the go trials, followed by the results for the nogo trials.

Go trials. Grand averages of the LRP for the gender-congruent and -incongruent condition are given in figure 4-1. Visual inspection of the go waveforms does not reveal any major deviations from baseline during the first 500 ms after prime onset. At around 500 ms a negativity starts up in both gender congruity conditions, getting a steeper slope from 650 ms on. It peaks at 800 ms with an amplitude of 2 μV and more, some 150 ms before the average response latency. This prominent negativity corresponds to the typical LRP signature of a unimanual response following an imperative stimulus. Statistical analysis with the serial t-test procedure estimated the onset of preparatory motor activity in the gender-congruent condition at 670 and 700 ms for the electrode pair 7/3 and 18/10, respectively. In the gender-incongruent condition the onset is estimated at 570 and 580 ms, for the two electrode pairs respectively. No further deviations from baseline were detected by the serial t-test procedure for the go conditions.

Nogo trials. Inspection of the grand average for the gender-congruent condition at electrode pair 7/3 shows some negative activity, which increases steadily from 400 ms on. The waveform parallels the start-up of the corresponding go waveform, before deviating from the latter at around 650 ms. For electrode pair 18/10, however, the nogo waveform of the condition has a different development, displaying a positive tendency from 200 to 600ms. In the gender-incongruent condition, electrode pair 7/3 shows a small negativity which starts at around 550 ms, 50 ms later than the respective go waveform, and decreases again from 650 ms on. Electrode pair 18/10 also displays a small negative peak in this condition, resembling the negativity described for electrode pair 7/3. It is followed by a positive deflection, from 750 to 1000 ms. Serial t-tests show a significant deviation from baseline only in the gender-congruent condition, for electrode pair 7/3, reflecting negative activity ranging from 600 to 700 ms. The moment where this nogo activity diverges from the corresponding go activity is at 700 ms, as indicated by a series of t-tests comparing the two conditions directly.

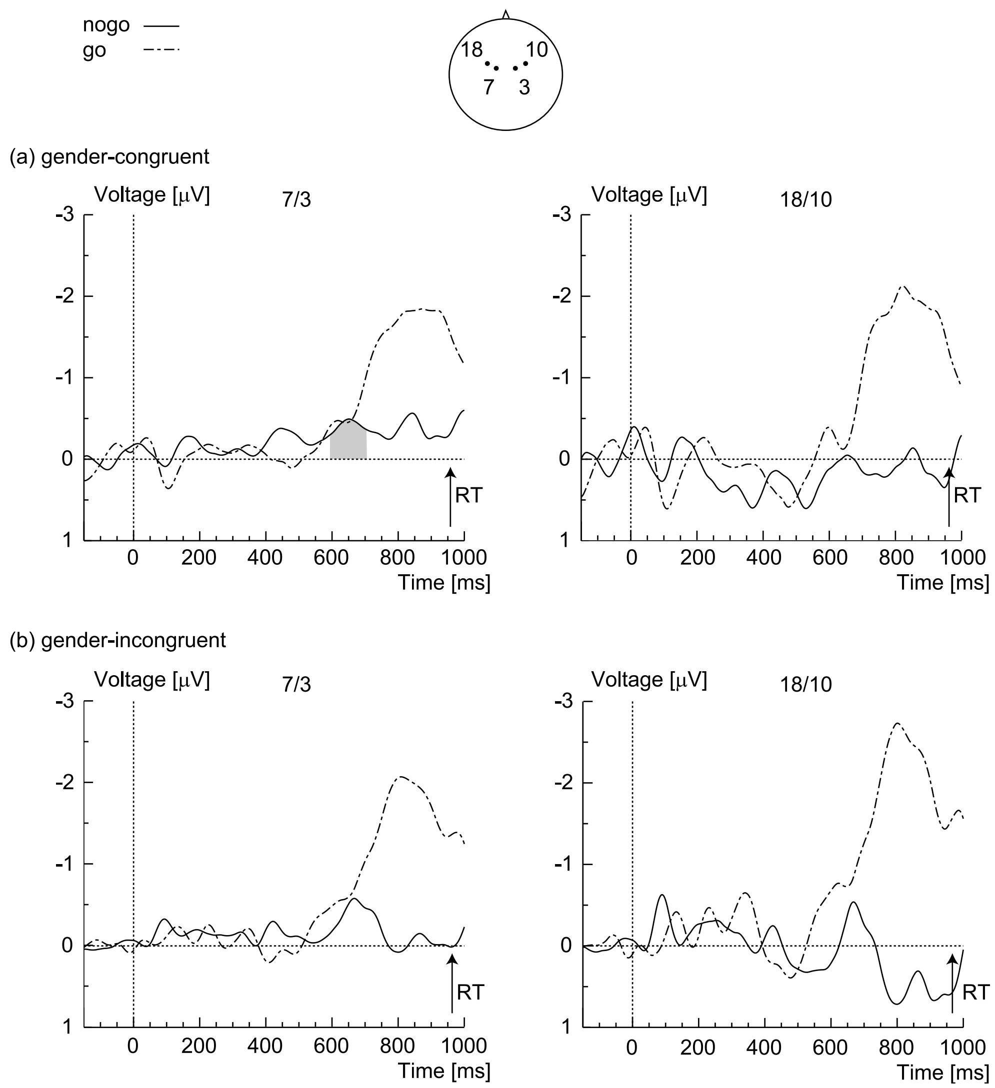

Figure 4-1. *Stimulus-locked LRPs for go and nogo trials, derived from the electrode pairs 7/3 and 18/10. Time = 0 ms corresponds to prime presentation and time = 100 ms to target presentation. Arrows indicate RT for go trials. (a) Condition with gender-congruent prime. The grey area underneath the nogo LRP for electrode pair 7/3 indicates the period where it deviates from baseline and parallels the development of the go LRP. (b) Condition with gender-incongruent prime.*

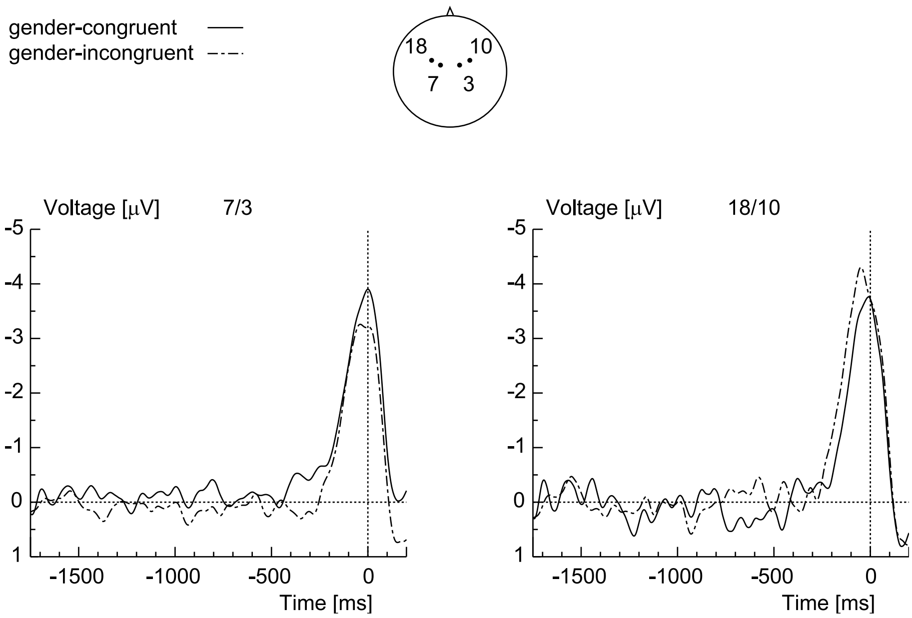

Figure 4-2. *Response-locked LRPs derived from electrode pairs 7/3 and 18/10, comparing the conditions with gender-congruent and gender-incongruent primes. Time = 0 ms corresponds to RT.*

Response-locked LRP

Time-locking occurred to the RT of go trials, which therefore represents time zero in this analysis. Clearly visible LRPs develop before response execution in the gender-congruent and -incongruent condition for both electrode pairs, with a peak around RT (see figure 4-2 for grand averages). In the gender-congruent condition, the LRP for electrode pair 7/3 shows an early negative increase at -400 ms and later the slope of the negativity becomes steeper, at around -250 ms. For the gender-incongruent condition no prominent deviations from baseline occur until the LRP starts up at around -250 ms. From -200 ms on, both waveforms develop in parallel. For electrode pair 18/10, the LRP of the congruent condition starts its ascend at around -200 ms, about 50 ms later than the incongruent waveform and maintains that difference. The serial t-test procedure estimates the onset of the response-locked LRP for electrode pair 7/3 in gender-congruent trials at -200 ms and in gender-incongruent trials at -160 ms. The onset estimates for electrode pair 18/10 are -180 ms for congruent and -200 ms for incongruent trials.

N2 effect

We now turn to the description of the go and nogo ERPs for the two gender congruity conditions, in relation to the N2 effect reported in the literature. The same basic morphology can be observed for the congruent and incongruent conditions at frontal electrode sites (see figure 4-3a and 4-3b for grand averages). A negative peak occurs at around 125 ms after prime presentation, followed by a positive peak at 200 ms, a negativity at 300 ms and a positivity at 350 ms. Finally, a negativity develops which peaks around 500 ms and is several microvolts bigger for the nogo than the go waveforms of both gender congruity conditions. We subtracted the go conditions from the nogo conditions to obtain net inhibition effects (see figure 4-3c). The subtraction waveforms for both congruity conditions show a big negative effect, which starts around 375 ms for the incongruent condition and around 425 ms for the congruent condition. The effects peak around 575 ms. Thus, at least the onset latency of the most prominent deflection seems to be earlier for the gender-incongruent than the gender-congruent condition.

Serial t-tests performed on the combined average of the five frontal electrodes indicate an onset latency of 480 ms for the gender-congruent condition and of 410 ms for the gender-incongruent condition. The peak latencies across the five frontal electrodes were 587 ms for the gender-congruent condition and 564 ms for the gender-incongruent condition. A univariate ANOVA was performed on the peak latencies, with the two within-subjects factors Gender congruity and Electrode (including the five frontal electrodes). The main effect of Gender congruity was significant ($F(1,15) = 6.2$, $MSE = 3368.9$, $p = .025$), while the main effect of Electrode was not ($F(4,60) = 1.6$, $MSE = 3066.0$, $p = .229$, $\varepsilon = .455$). A significant interaction between Task and Electrode ($F(4,60) = 3.7$, $MSE = 1189.9$, $p = .015$, $\varepsilon = .805$) modulated the main effects. We performed pairwise comparisons of the two congruity conditions for all five frontal electrodes, setting the comparisonwise alpha error rate at .01 to attain a familywise error rate of .05 (Bonferroni correction). Only electrode 33 (on the outer left side) showed a significant difference ($t(15) = 4.6$, $SE = 13.0$, $p < .001$), with a peak latency of 613 ms in the congruent condition and 554 ms in the incongruent condition.

Discussion

In this study, we manipulated the gender congruity of visually presented prime-target word pairs in order to examine the possibility of speeding up access to grammatical gender in relation to semantic information. This also concerns the issue whether the two retrieval processes are arranged in a serial discrete or parallel manner, since only the latter option allows for a change of retrieval order.

RTs showed a 6 ms advantage for gender-congruent over gender-incongruent trials, which was not significant. Likewise, accuracy data on go and nogo trials displayed no reliable

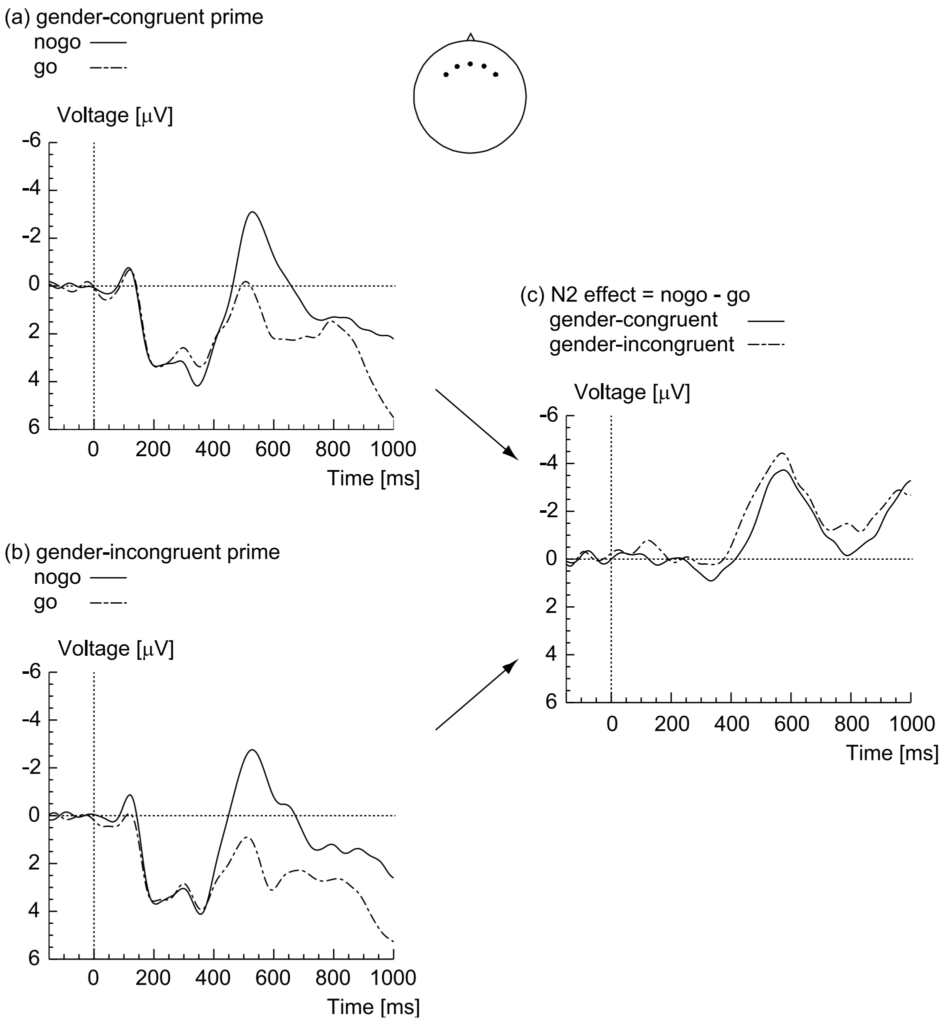

Figure 4-3. *ERPs of nogo and go trials, for (a) the gender-congruent and (b) the gender-incongruent condition, averaged over the five frontal electrodes as indicated on the bird's-eye view of the head. (c) N2 effect, subtraction waveforms (nogo - go) for the gender-congruent and gender-incongruent condition.*

effect of the gender congruity manipulation. In an earlier study, where participants performed simple gender decisions on identical material (chapter 3), we had found a 20 ms gender congruity effect for RT. It seems that this effect is now reduced in the two-choice go/nogo task. Such an outcome corresponds to the predictions made for parallel retrieval, with gender being available earlier than semantics in the congruent condition. The reduction is expected, because the launching of an overt response in the two-choice go/nogo task can not occur immediately after the availability of gender but has to wait until semantic information establishes the go status of the trial. The portion of the gender priming effect which falls into this waiting period would not be visible in RTs. In contrast, if retrieval of word properties took place in discrete stages, priming effects on any stage would influence RT in an additive manner, preserving the effect found for simple gender decisions. In the absence of a behavioral gender congruity effect, the ERP measures should still provide a window on the impact of gender congruity, tapping into processes before response execution.

Before turning to the ERP results we have to discuss the effect of grammatical gender on behavioral performance, with faster and more accurate responses to common than neuter gender targets. The two sets of words differed only marginally in length, with common gender words counting 5.1 letters on average and neuter gender words 5.3 letters. The average lemma frequency (per million; CELEX Dutch database, 1990) for common gender words was 24.9 and 50.1 for neuter gender words. As higher frequency is usually associated with faster and more accurate performance, this goes against the tendency in the behavioral measures. We undertook additional analyses, taking into account the neuter gender data from the whole experimental session and partitioning the session into four parts, which reflected the repetition of words and switches in response hand assignment. Regarding RT, this revealed that the difference between common and neuter gender targets originated in the second quarter of the session. In that part neuter gender targets were repeated under a switched response hand assignment while the particular common gender targets were presented for the first time. It may be that at least for some of the neuter gender targets, the previous episodes with the opposite response hand assignment caused interference. In contrast to RT, the common gender advantage in accuracy stayed constant over the whole experimental session. Considering that about three quarter of Dutch nouns have common gender (Van Berkum, 1996), it is possible that this dominance of common gender in the gender distribution has put neuter gender targets at a general disadvantage. Alternatively, gender assignment might have been harder for the particular set of neuter gender words in our study than for the common gender words. Crucially concerning our investigation of gender priming, there was no significant interaction involving gender congruity and target gender.

We now come to the ERP results, beginning with the LRP. We coupled grammatical gender to respond hand choice, in order to monitor early gender activation via LRP activity. If gender retrieval for targets indeed occurred faster after gender-congruent than gender-incongruent primes, information about the required response hand would be available earlier in the congruent condition which should be visible as an earlier onset of the stimulus-locked go LRP. This holds for both a serial discrete and a parallel architecture. However, the onset in the congruent condition occurred about 100 ms later than in the incongruent condition. According to the rationale laid out above, this would indicate that grammatical gender is available earlier when the target is preceded by a prime of the opposite rather than the same gender. In addition to contradicting our predictions, this sounds counter-intuitive. We will address this point later, after summarizing the results from the stimulus-locked nogo LRPs.

The stimulus-locked LRP in the nogo conditions can provide evidence on the relative timing of the retrieval of gender and semantic category. This also relates to the issue whether these retrieval processes are arranged in a serial discrete or parallel manner. A serial discrete architecture with gender being retrieved before semantic category can already be excluded, as the study in chapter 2 and Schmitt, Rodriguez-Fornells et al. (2001) found evidence that semantic category is available earlier than gender when words are presented in isolation. This leaves a serial discrete architecture where retrieval of the semantic category occurs before retrieval of gender can start. By definition, priming can not change the retrieval order in such a system. Thus, the semantically determined nogo information should always be available earlier than the left/right information determined by gender, preventing the development of a nogo LRP. However, a parallel architecture allows for a flexible retrieval order. If gender-congruent primes succeeded in making gender available earlier than semantic information, information about the demanded response hand would be available before information about the trial's nogo status. Hand-specific movement preparation could start, appearing as LRP activity, and would be halted as nogo information arrives. In the incongruent condition, gender retrieval should be slower and finish after semantic retrieval, so that the early nogo information would prevent the development of a nogo LRP. We indeed found significant LRP activity in the gender-congruent nogo condition for electrode pair 7/3, from 600 to 700 ms after prime presentation, whereas no significant LRP activity was diagnosed in the nogo condition for incongruent trials.

Although the nogo LRP results fit with the predictions for a parallel architecture, they are not in line with the go LRP findings. As the go LRPs seem to indicate that hand-specific response preparation occurred earlier in the incongruent than the congruent condition, one would expect to find nogo LRP activity in the incongruent rather than the congruent condition. Yet, we found the opposite. There have been other studies using the two-choice go/nogo task where the occurrence of a nogo LRP was inconsistent with the go LRP onset latencies. Schmitt et al. (2000) found an earlier go LRP onset when phonology determined response hand than when semantics did. Although the go LRP results seemed to indicate that phonology was available before semantics, they detected significant nogo LRP activity when semantics determined response hand and phonology determined response execution. A similar data pattern occurred in Schmitt, Schiltz, Zaake, Kutas, and Münte (2001), concerning the retrieval of conceptual and syntactic information in picture naming. One has to acknowledge, though, that in those cases the onset difference of the go LRPs was smaller than in the current study, namely around 50 ms rather than 100 ms.

The current study, thus, is not the only one showing some inconsistency between go and nogo LRPs, but we also have to consider that some property of our design might have led to these contradictory results. There is a feature of prime-target relations which could help explain the pattern of results: Prime and target always came from the opposite semantic category within a block, creating a constant semantic incongruity. [2] Semantic category determined the go/nogo decision in the current study, so that pairing words from opposite categories meant that go targets were always preceded by nogo primes and nogo targets by go primes. The go/nogo status of primes might have modulated their influence on the processes of response planning. One could imagine that the nogo status is generally associated with the suppression of response-related information extracted from a word, since nogo words should not be responded to. In contrast, the go status might be neutral towards the processing of response-related information or might even enhance it. This presupposes, of course, that the prime's go/nogo status is recognized. The semantic representation of a prime might have activated some task-related go or nogo representation which in turn modulated how the left/right information (derived from the prime's gender) was handled. For primes with nogo status (i.e., on trials with go targets), the gender information of the prime might have activated the corresponding response hand representation and the nogo status derived from semantics would lead to some inhibition of this representation. In case of gender-congruent go trials this would result in the temporary inhibition of the same hand representation which is activated by the target, leading to a delay. However, for a gender-incongruent go trial the inhibition based on the prime's nogo status would affect the opposite hand representation as the one activated by the target. In this way, gender-congruent trials could incur a disadvantage relative to gender-incongruent trials, leading to the difference in onset latencies for the go LRPs. Primes with go status (preceding nogo targets), however, should have no such inhibitory effects on response hand representations, since their semantic category is associated with executing a response. Therefore, the effects a prime has on gender retrieval should come through on nogo trials. Our predictions would

2. This was mainly done to create some additional disadvantage for semantic retrieval and make the development of nogo LRP actvity more likely. Furthermore, a systematic variation of semantic relatedness, that is, including prime-target pairs composed from the same semantic category as well as from opposite categories, would have doubled the number of trials. Although this additional manipulation might have resulted in interesting insights into the flexibility of the retrieval of word properties, it would have led to a substantial lengthening of the experimental session. In addition, since the pool of suitable words was already exhaustively used in the simpler design we used, the need for more trials would have meant to allow more repetitions. This in turn could have introduced more repetition related effects hard to control for.

apply in this case and they would actually be in line with finding nogo LRP activity in the congruent but not the incongruent condition, as mentioned above. Note, that the scenario for the go trials also concerns the interpretation of the RT results. The reduced gender congruity effect might have been the consequence of the delay on congruent trials and not that of a parallel architecture.

Priming gender retrieval would also affect the onset of the response-locked LRP in a parallel architecture, but not in a serial discrete architecture. The duration of the onset-to-response interval depends on the time which passes between the start of hand-specific response preparation and the decision to execute the response (assuming all succeeding processes have a constant duration across conditions). In our task, one can relate hand-specific response preparation to grammatical gender and response execution to semantic category. Given a serial discrete arrangement with semantic retrieval before gender retrieval, information about response execution would be available before information about response hand in any case, so that the onset-to-response interval can not be shortened. In a parallel arrangement, where gender is available earlier than semantic category in the congruent condition but available later in the incongruent condition, the distance between LRP onset and the triggering of response execution would be bigger for the congruent than the incongruent condition. The onset-to-response interval of the LRP for electrode pair 7/3 is actually 40 ms longer for the congruent than the incongruent condition. However, it is 20 ms shorter for electrode pair 18/10, leaving us with conflicting evidence. Furthermore, interpreting go LRP onsets as reflecting the timing of gender retrieval may be problematic in this study, as we argued above in our discussion of the stimulus-locked LRP results.

We now turn to the N2 effect which reflects a more negative ERP on the nogo trials relative to the go trials. Similar effects in go/nogo tasks have been interpreted as response inhibition (Eimer, 1993; Falkenstein et al., 1999; Jodo & Kayama, 1992; Kok, 1986) or conflict monitoring (Donkers & Van Boxtel, 2004; Nieuwenhuis et al., 2003). We had no firm predictions concerning the N2 effect, but expected that it would provide information about task-related aspects of executive functioning. The onset of the effect at frontal electrodes occurred 70 ms earlier for the gender-incongruent than the gender-congruent condition. Likewise, the peak latency was earlier for the incongruent than the congruent condition, though the difference was smaller, about 20 ms across the frontal electrodes. Although the manipulation of gender congruity is not directly related to the semantically determined go/nogo decision, it nevertheless seems to have had an influence. One could argue that more inhibitory control is needed in case of a gender-incongruent prime-target pair, because it is associated with two response tendencies, one triggered by the prime and the other by the target. With a gender-congruent pair, there is only one response tendency which has to be inhibited. The higher need for inhibitory control might be expressed in a faster build-up of activation which would explain the earlier onset and peak latencies of the N2 effect in the gender-incongruent condition. A similar line of reasoning can be adopted for the conflict monitoring perspective: Gender-incongruent prime-target pairs provide divergent gender and response hand information, leading to more conflict. The idea that divergent response tendencies can lead to an enhanced N2 effect matches with findings from the Eriksen flanker task, where an N2 has been observed in the incongruent condition, with target and distractors indicating different responses (Heil, Osman, Wiegelmann, Rolke, & Hennighausen, 2000; Kopp, Mattler, Goertz, & Rist, 1996).

It is further noteworthy that Abdel Rahman, Van Turennout, and Levelt (2003) conducted a study on object naming employing the two-choice go/nogo task, where a difficulty manipulation that aimed at the left/right decision also had an unexpected influence on the N2 peak latency. Participants saw pictures of animals and objects, with a semantic decision determining response hand and the second phoneme of the name determining response execution. In some blocks the semantic decision was constantly an animacy classification (blocked condition), while in other blocks there were two alternative classification schemes, an animacy and an aquatic/non-aquatic classification, prescribed on a trial-by-trial basis (mixed condition). The mixed condition led to slower animacy classifications, but also to an earlier N2 peak latency than in the blocked condition, even though the go/nogo decision depended on phonology. For the latter, Abdel Rahman et al. offer explanations which remain within the language processing domain, but we want to point out that the blocked/mixed effect can also be explained in terms of inhibition or conflict monitoring. The mixed condition additionally involves the choice between the animacy and the aquatic/non-aquatic classification scheme. This might include the inhibition of one scheme or the occurrence of competition, which would be picked up by the conflict monitoring system, leading to an earlier N2 effect in the mixed condition. From that perspective, the N2 latency differences in Abdel Rahman et al.'s and in our study would indicate that the N2 effect in two-choice go/nogo tasks is in a broad sense susceptible to task aspects involving inhibition or conflict monitoring, and not only to processing which is directly related to the go/nogo decision.

In summary, we investigated whether in language comprehension the order of gender and semantic category retrieval – semantics before gender for words presented in isolation – can be changed by gender priming. In a two-choice go/nogo task with gender determining response hand and semantic category determining response execution, we observed a nogo LRP in the gender-congruent condition. This provides evidence for gender being retrieved earlier than semantic category, that is, a reversal in retrieval order. By implication, this would mean that gender and semantic retrieval are arranged in a parallel rather than a serial discrete manner, since the latter does not allow for a reversal by definition. The picture was complicated by a difference in go LRP onset latencies, having a direction which ran against our predictions and was inconsistent with the nogo LRP results. We proposed a post-hoc explanation, considering that targets on go trials were always preceded by a prime of the nogo semantic category. This might have led to the inhibition of response tendencies from the prime, which would be especially harmful for gender-congruent trials because it would concern the same response as required for the target. Furthermore, the N2 effect, reflecting a more negative ERP on nogo than go trials, occurred earlier in the gender-incongruent than the gender-congruent condition, even though the go/nogo decision depended on semantics. We suggest this is the consequence of increased inhibitory control or conflict in the incongruent condition, where prime and target represented different response hands, while they represented the same response hand in the congruent condition. Interestingly, this could indicate a general sensitivity of the N2 effect to task demands, beyond the factors directly related to the go/nogo decision.

References

Abdel Rahman, R. (2001). *Organisation semantischer und phonologischer Repräsentationen in der Gesichtererkennung und Sprachproduktion: Elektrophysiologische Indikatoren paralleler Verarbeitung [Organization of semantic and phonological representations in face recognition and speech production: Electrophysiological indicators of parallel processing]*. Aachen: Shaker Verlag.

Abdel Rahman, R., & Sommer, W. (2003). Does phonological encoding in speech production always follow the retrieval of semantic knowledge? Electrophysiological evidence for parallel processing. *Cognitive Brain Research, 16,* 372-382.

Abdel Rahman, R., Sommer, W., & Schweinberger, S.R. (2002). Brain-potential evidence for the time course of access to biographical facts and names of familiar persons. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*, 366-373.

Abdel Rahman, R., Van Turennout, M., & Levelt, W.J.M. (2003). Phonological encoding is not contingent on semantic feature retrieval: An electrophysiological study on object naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*, 850-860.

American Electroencephalographic Society (1991). Guidelines for standard electrode position nomenclature. *Journal of Clinical Neurophysiology, 8,* 200-202.

Bates, E., Devescovi, A., Hernandez, A., & Pizzamiglio, L. (1996). Gender priming in Italian. *Perception & Psychophysics, 58*, 992-1004.

CELEX Dutch database (Release N31) [On-line]. (1990). Available at: http://www.mpi.nl/world/celex

Corbett, G.G. (1991). *Gender*. Cambridge: Cambridge University Press.

Dahan, D., Swingley, D., Tanenhaus, M.K., & Magnuson, J.S. (2000). Linguistic gender and spoken-word recognition in French. *Journal of Memory and Language, 42*, 465-480.

De Jong, R., Wierda, M., Mulder, G., & Mulder, L.J.M. (1988). Use of partial stimulus information in response processing. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 682-692.

Donkers, F.C.L. & Van Boxtel, G.J.M. (2004). The N2 in go/no-go tasks reflects conflict monitoring not response inhibition. *Brain and Cognition, 56*, 165-176.

Eimer, M. (1993). Effects of attention and stimulus probability on ERPs in a go/nogo task. *Biological Psychology, 35,* 123-138.

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (1999). ERP components in go/nogo tasks and their relation to inhibition. *Acta Psychologica, 101,* 267-291.

Friederici, A.D., & Jacobsen, T. (1999). Processing grammatical gender during language comprehension. *Journal of Psycholinguistic Research, 28*, 467-484.

Gratton, G., Coles, M.G.H., Sirevaag, E.J., Eriksen, C.W., & Donchin, E. (1988). Prestimulus and poststimulus activation of response channels: A psychophysiological analysis. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 331-344.

Heil, M., Osman, A., Wiegelmann, J., Rolke, B, & Hennighausen, E. (2000). N200 in the Eriksen-task: Inhibitory executive processes? *Journal of Psychophysiology, 14*, 218-225.

Jodo, E., & Kayama, Y. (1992). Relation of a negative ERP component to response inhibition in a go/nogo task. *Electroencephalography and Clinical Neurophysiology, 82,* 477-482.

Kok, A. (1986). Effects of degradation of visual stimuli on components of the event-related potential (ERP) in go/nogo reaction tasks. *Biological Psychology, 23,* 21-38.

Kopp, B., Mattler, U., Goertz, R., & Rist, F. (1996). N2, P3 and the lateralized readiness potential in a nogo task involving selective response priming. *Electroencephalography and Clinical Neurophysiology, 99*, 19-27.

Lippold, O.C.J. (1967). Electromyography. In P.H. Venables & I. Martin (Eds.), *A manual of psychophysiological methods* (pp. 245-297). Amsterdam: North-Holland Publishing Company.

McRae, K., Ferretti, T.R., & Amyote, L. (1997). Thematic roles as verb-specific concepts. *Language and Cognitive Processes, 12*, 137-176.

Nieuwenhuis, S., Yeung, N., Van den Wildenberg, W., & Ridderinkhof, K.R. (2003). Electrophysiological correlates of anterior cingulate function in a go/nogo task: Effects of response conflict and trial-type frequency. *Cognitive, Affective, & Behavioral Neuroscience, 3*, 17-26.

Osman, A., Bashore, T.R., Coles, M.G.H., Donchin, E., & Meyer, D.E. (1992). On the transmission of partial information: Inferences from movement-related brain potentials. *Journal of Experimental Psychology: Human Perception and Perception, 18,* 217-232.

Radeau, M., & Van Berkum, J.J.A. (1996). Gender decision. *Language and Cognitive Processes, 11*, 605-610.

Schmitt, B.M., Münte, T.F., & Kutas, M. (2000). Electrophysiological estimates of the time course of semantic and phonological encoding during implicit picture naming. *Psychophysiology, 37,* 473-484.

Schmitt, B.M, Rodriguez-Fornells, A., Kutas, M., & Münte, T.F. (2001). Electrophysiological estimates of semantic and syntactic information access during tacit picture naming and listening to words. *Neuroscience Research, 41,* 293-298.

Schmitt, B.M., Schiltz, K., Zaake, W., Kutas, M., & Münte, T.F. (2001). An electrophysiological analysis of the time course of conceptual and syntactic encoding during tacit picture naming. *Journal of Cognitive Neuroscience, 13*, 510-522.

Smid, H.G.O.M., Mulder, G., Mulder, L.J.M., & Brands, G.J. (1992). A psychophysiological study of the use of partial information in stimulus-response translation. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 1101-1119.

Theta/phi-coordinates of equidistant montage no. 10. (n.d.). Retrieved February 3, 2005, from http://www.easycap.de/easycap/e/downloads/M10_ThetaPhi.htm

Van Berkum, J.J.A. (1996). *The psycholinguistics of grammatical gender: Studies in language comprehension and production*. Nijmegen: Nijmegen University Press.

Van Turennout, M., Hagoort, P., & Brown, C.M. (1997). Electrophysiological evidence on the time course of semantic and phonological processes in speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 787-806.

SUMMARY AND CONCLUSIONS

Chapter 5

Language comprehension engages a diverse set of representations and processes in transforming a physical signal into a meaningful message. Perceptual processes lead to the identification of words, which are associated with semantic and syntactic properties. These form the basis for the construction of higher order structures at the sentence and discourse level. The interpretation also relies on general world knowledge, a model of the current discourse situation, and pragmatic knowledge about communicative intentions. Regarding such a complex activity, the coordination and timing of the different aspects plays an important role. The present study focused on the time course concerning the retrieval of semantic and syntactic word properties. This was investigated for written words occurring outside of sentence context. While semantic category served to probe retrieval of word meaning, grammatical gender functioned as an exemplary syntactic property. The experiment reported in chapter 2 used electrophysiological measures of brain activity to assess the retrieval order of semantic category and grammatical gender for single written words. Chapter 3 investigated the influence of a minimal context on the retrieval of grammatical gender. More specifically, it was examined whether the gender retrieval for a target noun would be influenced by presenting another noun that had congruent or incongruent gender. In chapter 4, the flexibility of the retrieval order for semantic category and grammatical gender was tested. The same electrophysiological method as in chapter 2 was applied, while employing the gender congruency manipulation from chapter 3 to alter the time course of gender retrieval.

Summary of Results

In the course of word recognition semantic and syntactic word properties become available. The issue addressed in chapter 2 was whether there is a particular retrieval order for semantic category and grammatical gender. Participants saw single Dutch nouns on a computer screen. The grammatical gender and semantic category of words determined responses in two different versions of a two-choice go/nogo task. In one version, grammatical gender cued response hand (left/right) for a push-button response and semantic category determined whether the response had to be executed or not (go/nogo). In the other version, the instructions were reversed: Semantic category cued response hand, while gender determined response execution.

Concurrent recordings of the electroencephalogram (EEG) were used to derive the lateralized readiness potential (LRP), which is an index of hand-specific response preparation. In both task versions, prominent LRP activity preceded overt responses in the go-condition. When semantic category determined response hand, there was LRP activity in the nogo-condition that started in parallel with the LRP in the go-condition, but soon returned to baseline. Thus, as semantic category became available, it was used to prepare the response for a specific hand in both the go- and the nogo-condition. The early decline of LRP activity in the nogo-condition reflects the setting in of response inhibition, based on grammatical gender. In short, response preparation could start up, before response inhibition occurred. This is in line with semantic category being available before grammatical gender. When grammatical gender determined response hand, both go- and nogo-condition showed some early LRP activity, temporally dissociated from the main LRP activity in the go-condition. Some fast guessing strategy regarding gender possibly led to this LRP activity, based on orthographic cues to gender in part of the stimulus set. Actual retrieval of grammatical gender from the lexicon most likely occurred around the time when the main LRP activity in the go-condition started. However, the nogo-condition showed no LRP activity in that period. It seems that the nogo-status, based on semantic category, was established before the lexical retrieval of grammatical gender could lead to hand-specific response preparation. The LRP results from both task versions indicate that lexical retrieval occurred earlier for semantic category than for grammatical gender.

Further, the N2 effect related to the go/nogo decision was examined. Both when semantic category and when grammatical gender determined the go/nogo decision, ERP activity in the nogo-condition became more negative than in the go-condition at a certain point. This is a characteristic pattern for go/nogo tasks, interpreted as stronger inhibitory activity or stronger response conflict for nogo-trials than for go-trials. In general, the divergence of nogo- and go-condition presupposes that the information determining the go/nogo decision is available, which allows inferences about the related time course. Separately for the two task versions, the N2 effect was computed by subtracting the go waveform from the nogo waveform. The N2 effect had an earlier peak latency when semantic category determined the go/nogo decision than when gender did. In summary, the analyses of both LRP and N2 effect indicated that the semantic word property was available before the syntactic word property for visually presented single words.

Chapter 3 focused on the retrieval of grammatical gender and how its time course could be influenced. Participants categorized visually presented nouns according to their grammatical gender in a reaction time task. Another noun was presented as prime at a SOA of 300, 100, or 0 ms. It could have the same gender (congruent) or the opposite gender (incongruent). At SOAs of 100 and 0 ms, gender categorizations were about 20 ms faster for congruent than incongruent primes. This shows that a gender congruent noun prime leads to faster gender retrieval than a gender incongruent noun prime. A possible mechanism for gender retrieval that could support such an effect was explored, in the form of a spreading activation network, where all words of a specific gender are linked to a common node representing the respective gender class. If prime and target were gender congruent, activation from both words would converge on the same gender node. In the gender incongruent case, activation would flow to different gender nodes. A retrieval process that includes competition among gender nodes would profit from a congruent prime and would suffer from an incongruent prime. The implementation of a network model with competitive gender selection, derived from WEAVER (Roelofs, 1992), was able to quantitatively capture the gender congruency effect of the reaction time study.

Chapter 4 deals with the question to what extent the retrieval order of semantic and syntactic word properties might be flexible. This directly relates to the issue whether retrieval of semantic and syntactic word properties is arranged in a serial discrete or parallel manner. If the arrangement is serial discrete, the order of retrieval stays constant by definition. If the arrangement is parallel, however, speeding up the slower retrieval process may lead to a reversed retrieval order. The experiment in chapter 2 had provided evidence that grammatical gender was available later than semantic category. Therefore, the retrieval of gender was targeted in a new ERP experiment with the two-choice go/nogo task, this time including gender congruent and gender incongruent primes to manipulate the retrieval time course. Grammatical gender determined response hand and semantic category determined the go/nogo decision. Again, the LRP was derived. When gender congruent primes were presented, transitory LRP activity occurred in the nogo-condition. This indicates that hand-specific response preparation based on gender took place before inhibition based on semantic category set in. This differed from the results in the gender incongruent condition and the comparable task version in chapter 2 (without primes), both of which showed no LRP activity in the nogo-condition related to lexical retrieval of gender. Finding a flexible retrieval order is in line with a parallel arrangement, while it contradicts a serial discrete arrangement.

The LRP activity in the go-conditions featured an unexpected result. The onset in the gender incongruent condition occurred about 100 ms earlier than in the gender congruent condition. Assuming that a gender congruent prime leads to faster gender retrieval than a gender incongruent prime, one would predict the opposite outcome. However, this pattern might have been an artifact caused by the semantic category of the prime. One has to consider that prime and target always came from the opposite semantic category within a block. As semantic category determined the go/nogo status that means a nogo target always occurred after a prime with go status and a go target always occurred after a prime with nogo status. In the case of go targets, the nogo status of the prime might have resulted in the inhibition of response tendencies related to the prime. For gender congruent trials, this would have led to the inhibition of the same response as for the target and therefore a delay of response preparation. This could explain the delayed onset latency of the LRP in the gender congruent condition.

General Discussion and Conclusions

The findings from chapter 2 provide evidence that semantic category is available before grammatical gender when single words are presented in written form. Schmitt, Rodriguez-Fornells, Kutas, and Münte (2001) investigated the same issue for single words presented in their spoken form, with German words that had to be categorized according to semantic category and grammatical gender. They also employed a two-choice go/nogo task, in which semantic category and gender were alternately mapped to response hand and go/nogo decision. The N2 effect occurred earlier when semantics determined the go/nogo decision than when gender determined the go/nogo decision, which matches with the findings for written words from chapter 2. Thus, it seems that the retrieval order of semantic category and gender for single words holds across modalities in language comprehension.

How do these findings relate to the retrieval of semantic and syntactic word properties in general? Semantic category and grammatical gender probe only particular parts of the semantic and syntactic representation of a word. The meaning of a word is represented as a single concept node in classical spreading activation networks (Collins & Loftus, 1975). Links exist to related concepts, which include the semantic category of a word. In such a localist network, the retrieval of semantic category does not probe the meaning of a word directly, but a concept that can be assumed to be temporally close. Distributed models of semantic representation conceptualize the meaning of a particular word as the activation of a set of semantic features (e.g., Plaut & Shallice, 1993). Members of the same semantic category typically show overlap in activation patterns, which can give rise to semantic categories in a network without their explicit implementation (Small, Hart, Nguyen, & Gordon, 1995). As in spreading activation networks, the availability of semantic category is not identical to the availability of a particular word meaning, but closely correlated. Neuropsychological research provides crucial empirical motivation for the role of semantic categories in theories of semantic representation, with the finding of category-specific deficits (cf. Caramazza, 2000). Further, semantic category relations show an effect in semantic priming studies, even though it is sometimes claimed that the evidence for their relevance in automatic priming is weak (cf. Lucas, 2000; Hutchison, 2003). Overall, both theoretical and empirical work lends credible support for using semantic category as a general probe into the retrieval of semantic word properties.

The relation of grammatical gender to other syntactic word properties is less well explored. One might borrow the notion of lemma from speech production research. A lemma is a syntactic word unit, which is linked to all syntactic properties (e.g., Roelofs, 1992). In such a conceptualization, the retrieval time course for grammatical gender could be assumed to be representative for all other syntactic properties. However, one should keep in mind that the syntactic properties linked to a lemma can be quite different. Whereas grammatical gender and lexical category can be assumed to be constant properties of a word, a diacritic feature such as number (singular/plural) has to be determined for each occurrence of a word.

A temporal difference between the retrieval of two word properties does not necessarily imply that retrieval occurs in a serial discrete manner, that is, with a fixed order (cf. Abdel Rahman, Sommer, & Schweinberger, 2002; Abdel Rahman, Van Turennout, & Levelt, 2003). Such a finding still allows for a parallel architecture, where retrieval of the two properties is independent and retrieval order is flexible. In a parallel architecture, speeding up the retrieval of the slower property or delaying the retrieval of the faster property can lead to a reversed retrieval order. This was the background for the experiment in chapter 4. Presenting gender congruent primes was supposed to speed up the retrieval of grammatical gender with respect to semantic category and lead to a different retrieval order as in chapter 2. The finding that in the gender congruent condition LRP activity occurred for nogo trials, whereas that had not been the case in the corresponding task in chapter 2, offers evidence for a reversed retrieval order and in consequence for a parallel architecture.

Findings regarding the arrangement of semantic and syntactic word properties in language comprehension can also have consequences for the notion that language production and comprehension might share semantic and syntactic representations. If such findings were incompatible with assumptions in speech production theories, one would have to reject that notion. The sharing of semantic and syntactic representations has been proposed in speech production research, often in relation to the fact that perceived language material can influence production processes (Branigan, Pickering, & Cleland, 2000; Levelt, Roelofs, & Meyer, 1999). Many accounts of speech production assume that the specification of word properties proceeds from a semantic level to a lemma level, which contains the syntactic properties, and from there to a phonological level (Dell, 1986; Harley, 1993; Kempen & Hoenkamp, 1987; Levelt, 1989; Levelt, et al., 1999; Stemberger, 1985). Given that the general direction of processing is reversed in language comprehension as compared to production, one would expect that in language comprehension syntactic word properties become available before semantic word properties. However, chapter 2 and the study by Schmitt et al. (2001) provided evidence to the contrary. Nonetheless, under very specific conditions, a system where activation from a perceived word reaches the lemma level before the semantic level can still accommodate this finding. First, the retrieval of syntactic and semantic word properties would have to occur in parallel. That means that lemmas and associated syntactic word properties would receive activation first, but at the same time activation would be passed on to the semantic level. Second, the use of gender and semantic category information for response preparation or inhibition would have to depend on the activation levels of the corresponding nodes reaching a critical threshold. Finally, activation for semantic category would have to build up at a faster rate than for gender. In such a scenario, semantic category might reach the critical threshold before grammatical gender, leading to the observed result pattern. The WEAVER model of speech production actually offers this possibility (Roelofs, 1992, 2003). As described in chapter 2, Roelofs (personal communication) implemented a version adapted for comprehension and was able to simulate the retrieval order. In WEAVER, gender nodes receive input from a lemma via a unidirectional link, whereas semantic category nodes share bidirectional connections with several other concept nodes in an extended semantic network. In this network, activation can reverberate, leading to a fast increase in the activation levels of the semantic category nodes.

The results from chapter 4 also bear on this issue. Finding evidence for parallel retrieval keeps the door open for a system with shared semantic and syntactic representations. It confirms the first of the three crucial conditions listed above. However, one should not forget that the evidence is also in line with a parallel architecture, where activation first reaches a semantic level, from which activation is passed on to a level containing syntactic information. Yet, one cannot decide between these alternatives on the basis of the data in this thesis.

Time Course in Retrieval of Word Properties and in Parsing

Research on the construction of higher level syntactic representations (i.e., parsing) features different proposals regarding the time course with which syntactic and semantic information can affect parsing. An interesting question is to what extent the different positions align with the time course findings in this thesis concerning the retrieval of word properties. One might speculate that an optimally designed comprehension system shows a close temporal coupling between the retrieval of word properties and their usage in the construction of higher level representations. Syntax-first models, as their name suggests, give precedence to syntactic information (Forster, 1979, Frazier, 1989; Friederici, 1995, 2002). This does not fit with respect to the retrieval of word properties for single words, given that the experiment in chapter 2, as well as the study by Schmitt et al. (2001), found evidence that semantic information is available before syntactic information. Forster assumes in a very general sense that lexical syntactic information is used before lexical semantic information, so one can safely say that the single word data and Forster’s proposal do not match. The models of Frazier and Friederici specifically point towards lexical category as the determinant of the first parsing attempt, while semantic and other syntactic information from the lexicon can exert an influence later. This makes a direct comparison with the existing single word data difficult, since lexical category was not tested. However, it suggests that lexical category and other syntactic word properties might have a differential retrieval time course. Friederici (2002; see her figure 1) indicates that identification of the word form is followed by identification of word category (i.e., lexical category), which is followed by the identification of the lemma and morphologic information. In this specific model, lexical category seems to be represented apart, while all other syntactic word properties are associated with the lemma. In contrast to syntax-first models, the so-called constraint-based models assume no fixed order for using a particular kind of information in parsing (MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell & Tanenhaus, 1994). As such, they can in principle accomodate any order in the availability of semantic and syntactic word properties. In general, one has to consider that the retrieval of word properties and the associated time course might change under the influence of a sentence context. There is, of course, an extensive literature on priming effects created by single word and sentence contexts. Within this thesis, the experiments in chapter 3 and 4 have shown that a minimal context can have an impact on the retrieval time course of word properties.

References

Abdel Rahman, R., Sommer, W., & Schweinberger, S.R. (2002). Brain-potential evidence for the time course of access to biographical facts and names of familiar persons. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*, 366-373.

Abdel Rahman, R., Van Turennout, M., & Levelt, W.J.M. (2003). Phonological encoding is not contingent on semantic feature retrieval: An electrophysiological study on object naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*, 850-860.

Branigan, H.P., Pickering, M.J., & Cleland, A.A. (2000). Syntactic co-ordination in dialogue. *Cognition, 75*, B13-B25.

Caramazza, A. (2000). The organization of conceptual knowledge in the brain. In M.S. Gazzanigga (Ed.), *The new cognitive neurosciences* (2nd ed., pp. 1037-1047). Cambridge, MA: MIT Press.

Collins, A.M., & Loftus, E.F. (1975). A spreading activation theory of semantic representation. *Psychological Review, 82*, 407-428.

Dell, G.S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review, 93*, 283-321.

Forster, K.I. (1979). Levels of processing and the structure of the language processor. In W.E. Cooper & E.C.T. Walker (Eds.), *Sentence processing: Psycholinguistic studies presented to Merrill Garrett* (pp.27-85). Hillsdale, NJ: Erlbaum.

Frazier, L. (1989). Against lexical generation of syntax. In W.D. Marslen-Wilson (Ed.), *Lexical representation and process* (pp. 505-528). Cambridge, MA: MIT Press.

Friederici, A.D. (1995). The time course of syntactic activation during language processing: A model based on neuropsychological and neurophysiological data. *Brain and Language, 50,* 259-281.

Friederici, A.D. (2002). Towards a neural basis of auditory sentence processing. *Trends in Cognitive Sciences, 6,* 78-84.

Harley, T.A. (1993). Phonological activation of semantic competitors during lexical access in speech production. *Language and Cognitive Processes, 8,* 291-309.

Hutchison, K.A. (2003). Is semantic priming due to association strength or feature overlap? A microanalytic review. *Psychonomic Bulletin & Review, 10*, 785-813.

Kempen, G., & Hoenkamp, E. (1987). An incremental procedural grammar for sentence formulation. *Cognitive Science, 11*, 201-258.

Levelt, W.J.M. (1989). *Speaking: From intention to articulation*.Cambridge, MA: MIT Press

Levelt, W.J.M., Roelofs, A., & Meyer, A.S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences, 22,* 1-75.

Lucas, M. (2000). Semantic priming without association: A meta-analytic review. *Psychonomic Bulletin & Review, 7*, 618-630.

MacDonald, M.C., Pearlmutter, N.J., & Seidenberg, M.S. (1994). Lexical nature of syntactic ambiguity resolution. *Psychological Review, 101,* 676-703.

Plaut, D.C., & Shallice, T. (1993). Deep dyslexia: A case study of connectionist neuropsychology. *Cognitive Neuropsychology, 10*, 377-500.

Roelofs, A. (1992). A spreading-activation theory of lemma retrieval in speaking. *Cognition, 42,* 107-142.

Roelofs, A. (2003). Goal-referenced selection of verbal action: Modelling attentional control in the Stroop task. *Psychological Review, 110*, 88-125.

Schmitt, B.M, Rodriguez-Fornells, A., Kutas, M., & Münte, T.F. (2001). Electrophysiological estimates of semantic and syntactic information access during tacit picture naming and listening to words. *Neuroscience Research, 41,* 293-298.

Small, S.L., Hart, J., Nguyen, T., & Gordon, B. (1995). Distributed representations of semantic knowledge in the brain. *Brain, 118*, 441-453.

Stemberger, J.P. (1985). An interactive activation model of language production. In A.W. Ellis (Ed.), *Progress in the psychology of language, Vol. 1* (pp. 143-186). London: Erlbaum.

Trueswell, J.C., & Tanenhaus, M.K. (1994). Toward a constraint-based lexicalist approach to syntactic ambiguity resolution. In C. Clifton, L. Frazier, & K. Rayner (Eds.), *Perspectives on sentence processing* (pp. 155-179). Hillsdale, NJ: Erlbaum.

SAMENVATTING

Taalbegrip vereist het omzetten van een fysiek signaal in een betekenisvolle boodschap. Hierbij wordt gebruik gemaakt van een diversiteit aan representaties en processen. Perceptuele processen leiden tot de identificatie van woorden, die met semantische en syntactische eigenschappen geassocieerd zijn. Deze eigenschappen vormen de basis voor de opbouw van structuren van een hogere orde, op het niveau van een zin of een heel gesprek. De interpretatie is ook afhankelijk van algemene wereldkennis, van de actuele gespreks-situatie en pragmatische kennis over communicatieve doelstellingen. Bij een dergelijke complexe activiteit spelen de coördinatie en het tijdsverloop van de verschillende aspecten een belangrijke rol. De huidige studie concentreerde zich op het tijdsverloop van het ophalen van semantische en syntactische eigenschappen van woorden. Dit werd onderzocht aan de hand van geschreven woorden die zonder een zinscontext werden aangeboden. De semantische categorie waartoe een woord behoord diende om de toegang tot woord-betekenis te onderzoeken en het grammaticale geslacht van een woord (b.v. *de melk* en *het zout*) werd als een exemplarische syntactische eigenschap gebruikt. In het experiment dat in hoofdstuk 2 wordt gerapporteerd, werden elektrofysiologische metingen van hersen-activiteit ingezet om de volgorde van het ophalen van de semantische categorie en het grammaticale geslacht voor geschreven woorden die in isolatie werden aangeboden te onderzoeken. In hoofdstuk 3 werd onderzocht wat de invloed is van een minimale context op het ophalen van het grammaticale geslacht van een woord. Meer specifiek werd er onderzocht of het ophalen van het geslacht voor een zelfstandig naamwoord beïnvloed kan worden door de presentatie van een ander zelfstandig naamwoord (een zogenaamde "prime"), dat wel of niet in geslacht overeenkomt. In hoofdstuk 4 werd de flexibiliteit van de volgorde getest, waarin de semantische categorie en het grammaticale geslacht worden opgehaald. Hierbij werd gebruik gemaakt van dezelfde elektrofysiologische methode als in hoofdstuk 2 en werden net als in hoofdstuk 3 primes aangeboden die qua grammaticaal geslacht wel of niet overeenkwamen, om zo het tijdsverloop van het ophalen van het grammaticale geslacht te manipuleren.

Samenvatting van de Resultaten

In de loop van het proces van woordherkenning komen de semantische en syntactische eigenschappen van een woord beschikbaar. In hoofdstuk 2 werd de kwestie behandeld of er een bepaalde volgorde bestaat in het ophalen van de semantische categorie en het grammaticale geslacht van een woord. De proefpersonen zagen Nederlandse zelfstandige naamwoorden op het computerscherm die één voor één werden aangeboden. Het grammaticale geslacht en de semantische categorie van een woord bepaalden de te geven reactie in twee verschillende versies van een tweevoudige classificatietaak. In de ene versie gaf het grammaticale geslacht aan welke hand gebruikt moest worden voor een drukknopreactie (links/rechts), terwijl de semantische categorie bepaalde of de reactie wel of niet uitgevoerd moest worden (go/nogo). In de andere versie werden de instructies omgekeerd: Nu gaf de semantische categorie de hand aan waarmee gereageerd moest worden en het geslacht bepaalde of de reactie uitgevoerd moest worden.

Tijdens het uitvoeren van deze tweevoudige classificatietaak werd het elektro-encefalogram (EEG) geregistreerd. De EEG registraties werden gebruikt om de ‘lateralized readiness potential’ (LRP) te berekenen. De LRP is een index van handspecifieke reactievoorbereiding. In beide taakversies ging er een duidelijke LRP-activiteit vooraf aan de uitgevoerde reactie in de go-conditie. Toen de semantische categorie de reactiehand bepaalde was er ook LRP-activiteit in de nogo-conditie te zien. Deze activiteit liep aanvankelijk parallel aan het verloop van de LRP in de go-conditie van de zelfde taakversie, maar keerde snel naar de ‘baseline’ terug. Dat betekent dat toen de semantische categorie beschikbaar kwam, deze informatie in zowel de go-conditie als in de nogo-conditie gebruikt werd om de reactie voor een specifieke hand voor te bereiden. De vroege terugkeer van LRP-activiteit naar baseline in de nogo-conditie wijst op het inzetten van een reactieremming, gebaseerd op grammaticaal geslacht. Kortom, er kon in deze taakversie begonnen worden met reactievoorbereiding alvorens er een reactieremming optrad. Dit wijst op een tijdsverloop, waarbij informatie over de semantische categorie van een woord beschikbaar komt vóór het grammaticale geslacht. Toen in de andere taakversie het grammaticale geslacht de reactiehand bepaalde, toonden de go- en nogo-conditie wat vroege LRP-activiteit. Deze was in de tijd gescheiden was van de meest prominente LRP-activiteit in de go-conditie, die aan de uitegevoerde recatie vooraf ging. Een verklaring voor deze resultaten zou kunnen zijn dat proefpersonen op basis van orthografische regulariteiten in een deel van de stimulusreeks een initiële strategische gok namen betreffende het geslacht van het aangeboden woord. Het daadwerkelijke ophalen van het grammaticale geslacht uit het lexicon vond waarschijnlijk plaats rond de tijd dat de prominente LRP-activiteit in de go-conditie begon. De nogo-conditie toonde echter geen LRP-activiteit in die periode. Het lijkt erop dat de nogo-status, die op de semantische categorie is gebaseerd, vastgesteld werd alvorens het grammaticale geslacht uit het lexicon kon worden opgehaald en tot handspecifieke reactievoorbereiding kon leiden. De LRP resultaten van beide taakversies wijzen erop dat de semantische categorie beschikbaar kwam vóór het grammaticale geslacht.

Ook werd er gekeken naar het N2 effect, dat aan de go/nogo beslissing gerelateerd is. Onafhankelijk van of de semantische categorie of het grammaticale geslacht de go/nogo beslissing bepaalde werd de ERP activiteit in de nogo-conditie op een zeker moment negatiever dan in de go-conditie. Dit is een kenmerkend patroon voor go/nogo taken, dat geïnterpreteerd wordt als een sterkere remmende activiteit danwel een sterker reactieconflict in de nogo-conditie. In het algemeen veronderstelt het uiteenlopen van de ERPs in de nogo- en go-conditie dat informatie met betrekking tot de go/nogo beslissing beschikbaar is. Op basis hiervan kunnen wederom conclusies over het betreffende tijdsverloop worden getrokken. Het N2 effect werd voor de twee taakversies afzonderlijk berekend, door de go-golfvorm van de nogo-golfvorm af te trekken. Toen de semantische categorie de go/nogo beslissing bepaalde had het N2 effect een vroegere pieklatentie dan toen het grammaticale geslacht deze beslissing bepaalde. Samenvattend wezen de analyses van zowel LRP als N2 effect erop dat voor visueel gepresenteerde woorden de semantische eigenschappen die bij een woord horen eerder beschikbaar komen dan de syntactische eigenschappen.

Hoofdstuk 3 richtte zich op het ophalen van het grammaticale geslacht en hoe het tijdsverloop ervan zou kunnen worden beïnvloed. In een reactietijdtaak moesten proefpersonen visueel gepresenteerde zelfstandige naamwoorden op basis van hun grammaticaal geslacht categoriseren. Een ander zelfstandig naamwoord werd als prime gepresenteerd, met een SOA van 300, 100 of 0 milliseconden. Deze prime kon hetzelfde geslacht (congruent) of het tegenovergestelde geslacht (incongruent) hebben. Bij SOA's van 100 en 0 ms vond de classificatie in de congruente conditie ongeveer 20 ms sneller plaats dan in de incongruente conditie. Dit toont aan dat het aanbieden van een zelfstandig naamwoord met hetzelfde geslacht leidt tot het sneller ophalen van het grammaticale geslacht van een woord dan een prime met het tegenovergestelde geslacht. Aan de hand van een netwerkmodel met spreidende activatie werd onderzocht welk mechanisme voor het ophalen van het grammaticale geslacht een dergelijk effect zou kunnen veroorzaken. In dit netwerk zijn alle woorden van hetzelfde geslacht met een gemeenschappelijke knoop verbonden, die het desbetreffende geslacht representeert. Als 'prime' en doelstimulus hetzelfde geslacht hebben, zou de activatie van beide woorden op dezelfde geslachtsknoop convergeren. Als er sprake is van een verschillend geslacht, dan zou de activatie naar verschillende geslachtsknopen stromen. Een ophaalproces met concurrerende geslachtsknopen zou van een prime met overeenstemmend geslacht profiteren, maar zou lijden onder een prime met afwijkend geslacht. De implementatie van een netwerkmodel met concurrerende geslachtsselectie, afgeleid van WEAVER (Roelofs, 1992), kon het effect van primes met overeenstemmend en afwijkend geslacht repliceren.

Hoofdstuk 4 behandelt de vraag in welke mate de volgorde in het ophalen van semantische en syntactische eigenschappen van woorden flexibel is. Dit is direct gerelateerd aan de vraag of het ophalen van semantische en syntactische woordeigenschappen op een serieel-discrete of parallelle manier verloopt. Als het ophalen van de verschillende eigenschappen serieel-discreet verloopt, blijft de volgorde van ophalen per definitie constant. Als het ophalen parallel verloopt, kan versnelling van het langzamere ophaalproces leiden tot een omkering van de volgorde in het ophalen. Het experiment in hoofdstuk 2 had een aanwijzing geleverd voor de mogelijkheid dat het grammaticale geslacht van een woord later wordt opgehaald dan diens semantische categorie. Daarom werd geprobeerd om het ophalen van het geslacht te versnellen door de presentatie van een prime met overeenstemmend geslacht, zoals in hoofdstuk 3. Om te onderzoeken of de ophaalvolgorde hierdoor veranderd werd er opnieuw gebruik gemaakt van de tweevoudige classificatietaak in combinatie met de ERP methode. Het grammaticale geslacht bepaalde met welke hand gereageerd moest worden en de semantische categorie bepaalde de go/nogo-beslissing. Ook nu werd het LRP berekend. Wanneer er een prime werd aangeboden met hetzelfde geslacht als de doelstimulus, kwam er een kortstondige LRP-activiteit in de nogo-conditie voor. Dit wijst erop dat de handspecifieke reactievoorbereiding, gebaseerd op geslacht, plaatvond vóór de remming inzette, die op de semantische categorie gebaseerd moest worden. Dit resultaat verschilde van de resultaten in de conditie met prime van tegenovergesteld geslacht en de vergelijkbare conditie in hoofdstuk 2 zonder primes. Deze twee condities toonden geen LRP-activiteit in de nogo-conditie die in verband gebracht kon worden met het daadwerkelijk ophalen van het geslacht uit het lexicon. Het vinden van een flexibele ophaalvolgorde wijst op een parallelle organisatie, terwijl het een serieel-discrete organisatie tegenspreekt.

De LRP-activiteit in de go-condities liet een onverwacht resultaat zien. De LRP-activiteit in de incongruente conditie zette ongeveer 100 ms vroeger in dan de LRP-activiteit in de congruente conditie. Ervan uitgaande dat een prime met overeenstemmend geslacht leidt tot het sneller ophalen van het geslacht van de doelstimulus dan een prime met tegenovergesteld geslacht, zou men het omgekeerde resultaat verwachten. We vermoeden dat dit patroon het gevolg is van een artefact, dat veroorzaakt werd door de semantische categorie van de prime. De prime was altijd van de tegenovergestelde semantische categorie als de doelstimulus. Aangezien de semantische categorie de go/nogo beslissing bepaalde, betekent dit dat een prime met nogo-status altijd gevolgd werd door een go-doelstimulus en een prime met go-status altijd gevolgd werd door een nogo-doelstimulus. De nogo-status van een prime zou ertoe geleid kunnen hebben dat de tendens om met de hand te reageren die door het geslacht van de prime was aangewezen werd onderdrukt. Voor congruente go-trials zou dit geleid kunnen hebben tot de onderdrukking van een reactie met de hand die juist door de doelstimulus werd vereist en daardoor tot een vertraging van de reactievoorbereiding. Dit zou een verklaring kunnen zijn voor de vertraagde beginlatentie van de LRP in de congruente conditie.

Algemene Discussie and Conclusies

De bevindingen van hoofdstuk 2 duiden erop dat, wanneer zelfstandige naamwoorden in geschreven vorm in isolatie worden aangeboden, informatie over de semantische categorie van een woord beschikbaar komt vóór informatie over diens grammaticale geslacht. Schmitt, Rodriguez-Fornells, Kutas en Münte (2001) onderzochten dezelfde kwestie in het Duits voor woorden in gesproken vorm, die aan de hand van hun semantische categorie en grammaticaal geslacht moesten worden gecategoriseerd. Zij pasten ook een tweevoudige classificatietaak toe, waarin de semantische categorie en het geslacht afwisselend de reactiehand en de go/nogo-beslissing bepaalden. Het N2-effect kwam eerder voor wanneer de semantiek de go/nogo-beslissing bepaalde dan wanneer het geslacht deze beslissing bepaalde. Dit komt overeen met de bevindingen voor geschreven woorden in hoofdstuk 2. Het lijkt er dus op dat de volgorde voor het ophalen van de semantische categorie en het grammaticale geslacht voor woorden die in isolatie worden aangeboden hetzelfde is ongeacht de modaliteit waarin ze worden aangeboden.

Hoe verhouden de huidige bevindingen zich tot de kwestie van het tijdsverloop van ophalen van semantische en syntactische woordeigenschappen in het algemeen? De semantische categorie en het grammaticale geslacht vormen slechts een onderdeel van de semantische en syntactische representatie van een woord. De betekenis van een woord wordt in klassieke netwerkmodellen met spreidende activatie gerepresenteerd als één enkele conceptknoop (Collins & Loftus, 1975). Er bestaan verbindingen met gerelateerde concepten, waaronder ook de semantische categorie van een woord. In een dergelijk localistisch netwerk is de toegang tot de semantische categorie van een woord niet gelijk te stellen met de toegang tot de eigenlijke betekenis van het woord. Men kan echter veronderstellen dat de toegang tot de semantische categorie in temporaal opzicht dicht bij de toegang tot de eigenlijke betekenis ligt. In gedistribueerde modellen van semantische representatie wordt de toegang tot de betekenis van een bepaald woord voorgesteld als activatie van een reeks semantische eigenschappen (b.v., Plaut & Shallice, 1993). Typerend voor de leden van een semantische categorie is dat ze overlappende activatiepatronen vertonen. Deze overlap kan leiden tot semantische categoriestructuren in een gedistribueerd netwerk zonder dat de categorieën expliciet geïmplementeerd zijn (Small, Hart, Nguyen, & Gordon, 1995). Net als in localistische netwerken is de beschikbaarheid van de semantische categorie niet identiek aan, maar sterk gecorreleeerd met de beschikbaarheid van een bepaalde woordbetekenis. Neuropsychologisch onderzoek levert belangrijke empirische motivatie voor de rol van semantische categorieën in theorieën van semantische representatie, door de bevinding van categoriespecifieke stoornissen in een bepaalde groep patiënten met afasie (zie Caramazza, 2000). Verder tonen woorden van de zelfde semantische categorie een effect in semantische priming-studies, hoewel soms gesteld wordt dat de evidentie voor een relevante rol van deze relaties bij automatische priming zwak is (zie Lucas, 2000; Hutchison, 2003). Kort samengevat verleent zowel theoretisch als empirisch werk geloofwaardige steun aan het gebruik van semantische categorieën om het ophalen van semantische woordeigenschappen in een bredere zin te onderzoeken.

Hoe het grammaticale geslacht zich verhoudt tot andere syntactische woordeigenschappen is minder goed onderzocht. Men zou het concept van lemma uit onderzoek naar taalproduktie hiervoor kunnen lenen. Een lemma is een syntactische woordeenheid, die met alle syntactische eigenschappen verbonden is (b.v., Roelofs, 1992). In een dergelijke conceptualisering zou men kunnen aannemen dat het tijdsverloop van het ophalen van het grammaticale geslacht representatief is voor alle andere syntactische eigenschappen. Het is echter belangrijk om stil te blijven staan bij het gegeven dat de syntactische eigenschappen die met een lemma verbonden zijn, vrij verschillend kunnen zijn. Hoewel verondersteld kan worden dat het grammaticale geslacht en de lexicale categorie (werkwoord, zelfstandig naamwoord etc.) van een woord constante eigenschappen zijn, moet een diakritische eigenschap zoals numerus (enkelvoud/meervoud) voor elk voorkomen van een woord worden bepaald.

Een tijdsverschil tussen het ophalen van twee woordeigenschappen impliceert niet noodzakelijkerwijs dat het ophalen op een serieel-discrete wijze, dat wil zeggen met een vaste volgorde, plaatsvindt (zie Abdel Rahman, Sommer, & Schweinberger, 2002; Abdel Rahman, Van Turennout, & Levelt, 2003). Een dergelijke bevinding staat ook een parallelle architectuur toe, waar de twee eigenschappen onafhankelijk van elkaar worden opgehaald en de volgorde flexibel is. In een parallelle architectuur kan de volgorde worden omgekeerd door het ophalen van de later beschikbare eigenschap te versnellen of het ophalen van de eerder beschikbare eigenschap te vertragen. Dit was de achtergrond voor het experiment in hoofdstuk 4. Primes met overeenstemmend geslacht werden aangeboden om het ophalen van het grammaticale geslacht ten opzichte van de semantische categorie te versnellen, wat tot een andere volgorde in ophalen zou leiden als in hoofdstuk 2. De bevinding dat er LRP-activiteit optrad in de nogo-trials van de congruente conditie, terwijl dat niet het geval was geweest in de overeenkomstige taak in hoofdstuk 2, biedt evidentie voor een omgekeerde volgorde in het ophalen van semantische en syntactische eigenschappen van een woord en dus voor een parallelle architectuur.

Bevindingen op het gebied van de architectuur van semantische en syntactische woordeigenschappen in taalbegrip kunnen in principe gevolgen hebben voor de hypothese dat taalproductie en taalbegrip mogelijk semantische en syntactische representaties van woorden delen. Als dergelijke bevindingen niet verenigbaar zouden zijn met veronderstellingen in theorieën van taalproductie, zou men deze hypothese moeten verwerpen. Het delen van semantische en syntactische representaties is voorgesteld in onderzoek op het gebied van taalproductie, vaak in relatie tot het feit dat waargenomen taal productie-processen kan beïnvloeden (Branigan, Pickering, & Cleland, 2000; Levelt, Roelofs, & Meyer, 1999). Vele modellen van taalproductie veronderstellen dat de specificatie van woordeigenschappen van een semantisch niveau naar een lemmaniveau vloeit, dat de syntactische eigenschappen bevat, en van daaruit naar een fonologisch niveau (Dell, 1986; Harley, 1993; Kempen & Hoenkamp, 1987; Levelt, 1989; Levelt, et al, 1999; Stemberger, 1985). Aangezien de algemene richting van verwerking in taalbegrip omgekeerd is in vergelijking met taalproductie, zou men verwachten dat in taalbegrip de syntactische woordeigenschappen vóór de semantische woordeigenschappen beschikbaar komen. Hoofdstuk 2 en de studie door Schmitt et al. (2001) duiden echter op het tegendeel. Niettemin kan in zeer specifieke omstandigheden een systeem, waar de activatie van een waargenomen woord eerst het lemmaniveau en dan het semantische niveau bereikt, deze bevindingen toch verklaren. Ten eerste zou het ophalen van syntactische en semantische woordeigenschappen parallel georganiseerd moeten zijn. Dat betekent dat activatie eerst de lemma's en de bijbehorende syntactische woordeigenschappen bereikt, maar tegelijkertijd de activatie aan het semantische niveau wordt doorgegeven. Ten tweede zou het gebruik van informatie over het geslacht en de semantische categorie voor reactievoorbereiding of remming af moeten hangen van het bereiken van een bepaalde activatiedrempel. Tot slot zou de activatie voor de semantische categorie sneller moeten stijgen dan de activatie voor het grammaticale geslacht. In een dergelijk scenario zou de semantische categorie de kritieke drempel kunnen bereiken vóór het grammaticale geslacht, zodat het waargenomen patroon van resultaten ontstaat. Het WEAVER model van taalproductie biedt deze mogelijkheid inderdaad (Roelofs, 1992, 2003). Zoals beschreven in hoofdstuk 2 heeft Roelofs (persoonlijke communicatie) een voor taalbegrip aangepaste versie geïmplementeerd, die de volgorde van ophalen kon simuleren. In WEAVER ontvangen de geslachtsknopen input van een lemma door een eenrichtingsverbinding, terwijl de semantische categorieknopen tweerichtingsverbindingen met verscheidene andere conceptknopen in een uitgebreid semantisch netwerk delen. In dit netwerk kan de activatie weerkaatsen, wat tot een snelle verhoging van de activatieniveaus van de semantische categorieknopen leidt.

De resultaten van hoofdstuk 4 zijn ook van belang voor deze kwestie. De evidentie voor een parallelle organisatie houdt de mogelijkheid open voor een systeem met gezamenlijke semantische en syntactische representaties. Het bevestigt de eerste van de drie essentiële voorwaarden die hierboven vermeld staan. Men moet echter niet vergeten dat de evidentie ook consistent is met een parallelle architectuur, waar de activatie eerst het semantische niveau bereikt, vanwaar de activatie doorgegeven wordt aan een niveau dat syntactische informatie bevat. Op basis van de gegevens in dit proefschrift kan men echter niet tussen deze alternatieven beslissen.

Referentielijst

Abdel Rahman, R., Sommer, W., & Schweinberger, S.R. (2002). Brain-potential evidence for the time course of access to biographical facts and names of familiar persons. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*, 366-373.

Abdel Rahman, R., Van Turennout, M., & Levelt, W.J.M. (2003). Phonological encoding is not contingent on semantic feature retrieval: An electrophysiological study on object naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*, 850-860.

Branigan, H.P., Pickering, M.J., & Cleland, A.A. (2000). Syntactic co-ordination in dialogue. *Cognition, 75*, B13-B25.

Caramazza, A. (2000). The organization of conceptual knowledge in the brain. In M.S. Gazzanigga (Ed.), *The new cognitive neurosciences* (2nd ed., pp. 1037-1047). Cambridge, MA: MIT Press.

Collins, A.M., & Loftus, E.F. (1975). A spreading activation theory of semantic representation. *Psychological Review, 82*, 407-428.

Dell, G.S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review, 93*, 283-321.

Harley, T.A. (1993). Phonological activation of semantic competitors during lexical access in speech production. *Language and Cognitive Processes, 8,* 291-309.

Hutchison, K.A. (2003). Is semantic priming due to association strength or feature overlap? A microanalytic review. *Psychonomic Bulletin & Review, 10*, 785-813.

Kempen, G., & Hoenkamp, E. (1987). An incremental procedural grammar for sentence formulation. *Cognitive Science, 11*, 201-258.

Levelt, W.J.M. (1989). *Speaking: From intention to articulation*.Cambridge, MA: MIT Press

Levelt, W.J.M., Roelofs, A., & Meyer, A.S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences, 22,* 1-75.

Lucas, M. (2000). Semantic priming without association: A meta-analytic review. *Psychonomic Bulletin & Review, 7*, 618-630.

Plaut, D.C., & Shallice, T. (1993). Deep dyslexia: A case study of connectionist neuropsychology. *Cognitive Neuropsychology, 10*, 377-500.

Roelofs, A. (1992). A spreading-activation theory of lemma retrieval in speaking. *Cognition, 42,* 107-142.

Roelofs, A. (2003). Goal-referenced selection of verbal action: Modelling attentional control in the Stroop task. *Psychological Review, 110*, 88-125.

Schmitt, B.M, Rodriguez-Fornells, A., Kutas, M., & Münte, T.F. (2001). Electrophysiological estimates of semantic and syntactic information access during tacit picture naming and listening to words. *Neuroscience Research, 41,* 293-298.

Small, S.L., Hart, J., Nguyen, T., & Gordon, B. (1995). Distributed representations of semantic knowledge in the brain. *Brain, 118*, 441-453.

Stemberger, J.P. (1985). An interactive activation model of language production. In A.W. Ellis (Ed.), *Progress in the psychology of language, Vol. 1* (pp. 143-186). London: Erlbaum.

Curriculum Vitae

Oliver Müller (1972) studied psychology at the Technical University of Braunschweig, Germany, graduating in 1999. In the same year, he was granted a PhD stipendium from the German Max-Planck-Gesellschaft and joined the Max Planck Institute for Psycholinguistics in Nijmegen, The Netherlands. He was member of the "Neurocognition of Language" project at the Max Planck Institute and later at the F.C. Donders Centre for Cognitive Neuroimaging, Nijmegen. Currently, he is affiliated to the Cognitive Neuroscience and Psycholinguistics Team at the University of La Laguna, Spain.

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